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LECTURES
ON
NATURAL AND EXPERIMENTAL
PHILOSOPHY,

CONSIDERED IN ITS PRESENT STATE OF
IMPROVEMENT.

DESCRIBING IN A FAMILIAR AND EASY MANNER
THE PRINCIPAL PHENOMENA OF NATURE;

AND SHEWING
THAT THEY ALL CO-OPERATE IN DISPLAYING THE GOODNESS,
WISDOM, AND POWER OF GOD.

BY THE LATE
GEORGE ADAMS,
MATHEMATICAL INSTRUMENT MAKER TO HIS MAJESTY, &c.

IN FIVE VOLUMES,
The Fifth Volume consisting of the Plates and Index.

THE SECOND EDITION,
WITH CONSIDERABLE CORRECTIONS AND ADDITIONS, BY
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MATHEMATICAL INSTRUMENT MAKER.

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LECTURES
ON
NATURAL PHILOSOPHY.

ON

ASTRONOMY.

LECTURE XXXVII.

OF THE COPERNICAN SYSTEM.

HAVING shewn you the appearances of the heavenly bodies as seen from the earth, it will be now proper to shew you why the motions of the planets appear to us so different from what they really are. One of the ends for which man was formed, is to correct appearances and error by the investigation of truth; whoever considers him attentively from infancy to manhood, and from manhood to old age, will find him ever busy in endeavouring to find some reality to supply the place of those false appearances, by which he has hitherto been deceived. Thus, it is the business of the present Lecture to correct those errors that arise from appearances in the heavens, and to prove the truth of the *Copernican*

System, which is now generally received, because it rationally accounts for, and accords with, the phenomena of the heavens. In this system, the sun is placed in the center, and the earth and other planets revolve round him as their center.

There are, however, strong reasons for believing, that some of the sages of antiquity were acquainted with the true solar system as revived by *Copernicus.* It was the universal doctrine of the Pythagorean school, and is clearly marked out as such by *Aristotle:* for these, says he, assert, that fire is in the midst of the world, and that the earth is one of the heavenly bodies. He afterwards speaks of a set of men, who held a system essentially similar to that of the modern Semitychonic. *Eudemus*, in his history of astronomy, as cited by *Anatolius*, says, that *Anaximander* was the first who discovered the earth to be one of the heavenly bodies, and to move round the center of the world. *Aristarchus* held, that the earth is carried round the sun, in the circumference of a circle, of which the sun itself is the center; and that the sphere of the fixed stars is so immense, that the circle of the earth's annual orbit bears no greater proportion to it, than the center of any sphere bears to its whole surface. *Philolaus*, and others, declared the motion of the sun round the earth to be only apparent. They saw and felt the importance of his globe over ours, and, supposing its influence to extend to much larger bounds than that of the earth, they placed it in the center of the universe. Among the Romans we find, that *Numa* built a temple to represent, as *Plutarch* interprets it,* the system of the heavens, with a sacred fire in the center of it.

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* Those who want further information on this head, may consult the notes to *Sydenham*'s Translation of the Rivals of Plato, *Duten*'s Inquiries into the Origin of the Discoveries attributed to the Moderns; *Jones*'s Essay on the First Principles of Natural Philosophy; *Baillie* Histoire de l'Astronomie Ancienne.

Thus also in the Jewish tabernacle, the seven lights had a reference to the seven chief lights of the heavens. Hence also the heavens are called in sacred writ the tabernacle of the sun; the whole of our system dwelling within his influence. The foregoing citations, are, we presume, sufficient to shew, that the ancients were not ignorant of the true solar system.

But still it was no general persuasion, nor does it seem ever to have been mentioned after the time of *Ptolemy*, who adopted that system which now goes under his name, his system, though erroneous, was ingenious; with it the world was content for many ages. It was then considered as founded upon invincible demonstration; as a sacred truth that could not be weakened by the powers of controversy, or shaken by the fluctuations of opinion.

" But at the time appointed, when it pleased the Supreme Dispenser of good gifts to restore light to a bewildered world, and more particularly to manifest his wisdom in the simplicity as well as the grandeur of his works, he opened the scene with a revival of sound astronomy."*

This observation of the President of the Royal Society, is well worthy your attention; it will open your views of Divine Providence, which is a topic that ought to be set in every possible light that can make it either more clearly, or more generally understood. If you look through the history of past ages from the early periods of the pastoral and patriarchal life, you will see arts and sciences progressively advancing; sometimes indeed buried for a long interval, but again reviving with new splendor. You see philosophy and religion advancing, and though sometimes deformed by superstition, and unnatural systems of atheism, yet successively recovered from the dreams of the enthusiast, and the subtilety of the atheist. If you see scepticism and infidelity making frequent attacks upon sacred truths, you may rest satisfied, that these attempts will, in due time, magnify its power, increase its honors, and advance its triumphs.

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* Sir *John Pringle's* Six Discourses, p. 97.

There is no man but what, with respect to the arts and improvements of life, looks back with pity on past times, compared with his own; and philosophy never extended the province of human knowledge so far and wide as within the last century. It is thus also with divine knowledge; this had the same gradation and order of progression, nature and law, the type and the shadow, the substance and the archetype; the kingdom of God is still advancing, and the evidences of his administration and attributes still opening; every thing evinces that a grand design has been carrying on from the earliest account of history by a remarkable course of Providence, for the benefit of the whole human race.

SUMMARY VIEW OF THE SOLAR SYSTEM.

I shall now proceed to give you a summary view of the solar system, or that which was revived and drawn from oblivion by *Nicholas Copernicus*, about the year 1500. It is called the *solar system*, because the sun is supposed to be fixed in the center, with our earth, and several bodies similar thereto, revolving round him at different distances.

The *planets* are those bodies within our system that revolve round the sun; they appear bright by reflecting the light they receive from the sun, and divided by astronomers into three kinds, *primary planets*, *secondary planets*, and *comets*.

The *primary planets* are those bodies which, in revolving round the sun, respect him only as the center of their courses, the motions of which are regularly performed in tracks or paths that are found to be nearly circular and concentric to each other.

A *secondary planet*, commonly called a *satellite* or *moon*, is a body, which, while it is carried round the sun, does also revolve round a primary planet, which it respects as a center.

Comets are bodies, which are also supposed to revolve round the sun; the planets appear permanent in the system, but comets only occur accidentally: they are named comets from their being usually attended with long tails, fancied by some to resemble hair. The theory of their motions amounts at present to little better than rude conjecture.

The path described by a planet in its motion round the sun, is called its *orbit*.

In speaking of orbits, nothing more is meant than an imaginary circle defining the path they describe, and in which they are retained by a celestial but continuous mechanism.

There are seven primary planets usually reckoned in order from the sun; their names and marks are,

Mercury.	Venus.	The Earth.	Mars.	Jupiter.	Saturn.	Georgium Sidus.
☿	♀	⊕	♂	♃	♄	♅

Mars, Jupiter, Saturn, and the Georgium Sidus, are called *superior planets*, because their orbits include that of the Earth.

Venus and Mercury are called *inferior planets*, because their orbits are contained within the Earth's.

By the assistance of telescopes *secondary planets* have been discovered; the Earth is attended by one, Jupiter by four, Saturn by seven, and the Georgium Sidus by two.

This diagram, *plate* 1, *fig*. 1, *Astronomy*, represents the solar system; O, in the center, represents the sun, AB the circle described by Mercury in moving round the sun, CD that in which Venus moves, FG the orbit of the Earth, HK that of

Mars, I N that of Jupiter, O P the path of Saturn, Q R the orbit of the Georgium Sidus.

Every primary planet is supposed to have two motions, 1. The *annual*; 2. The *diurnal.*

The *annual motion* of a planet is that whereby it is carried in its orbit round the sun, which in every one is found to be in the same direction from west to east.

This motion, as you have seen, is discovered by the planets changing their places in the celestial sphere, where they appear to move among the fixed stars; and in certain times to return to the same stars from which they were seen to depart, and so on continually.

The *diurnal motion* of a planet is that by which it turns or revolves about its axis; this, like their annual motion, is from west to east.

This motion is discovered by the spots that are seen by telescopes on the surface of the planets; before the discovery of telescopes, it was not suspected that the planets had a rotatory motion.

By continued observation, the spectator finds, that these spots change their places, and move from one side of the planet to the other; then disappear for a certain space of time; after which, they again, for a while, become visible on the side where they were first seen, always continuing the same motion nearly in an uniform manner. The distance between the spots grows wider as they advance from the edge towards the middle of the planet, and then grows narrow again as they pass from the middle to the other edge. The time they are seen on the planet's disk, is somewhat less than the time of their disappearance; they are first seen on the eastern margin of the planet, and disappear on the western side or limb.

From these circumstances it is concluded, first, that these spots adhere to the body of the planet;

and, secondly, that each planet is a globe turning on its axis.

It may not be improper to observe to you, that the axis of a planet is only an imaginary line conceived to be drawn through its center, and about which it is conceived to turn in the course of its revolution round the sun. A ball, whirled from the hand in the open air, turns round upon a line within itself, while it is moving forward; such a line as this is meant when we speak of the axis of a planet.

The sun and moon, the stars and planets, appear to be all at an equal distance from us; though it is highly probable, that some of the stars are many millions of times nearer to us than others. The sun is demonstrated to be nearer than any of the stars. The moon and some of the planets are known by ocular proof to be nearer to us than the sun, because they sometimes come between it and our eye, and hide the whole, or a great part of his disk from our view. They all, however, appear equally distant, and as if placed in the surface of a sphere, whereof our eye is the center. In whatever place, therefore, a spectator resides, whether it be on this earth, in the sun, or in the regions of Saturn, he will consider that place as the center of the world; for it will be to him the center of a spherical surface, in which all distant bodies appear to be placed; for while he remains in the same place, he cannot judge properly of the distance of surrounding objects, at least of those which are placed beyond the ordinary reach of his view; for beyond that distance all the principles by which we form our general judgment fail us, and we can only tell which is nearest, or that which is furthest, by our own motion, or that of the objects.

To illustrate this, let us suppose a number of lamps to be placed irregularly at different distances from the eye in a dark night. Now, if in this case we suppose the darkness to be so complete that no intermediate objects can be seen, no difference in colour observed, nor any perception of a convergence towards the point of sight, our judgment could not assist us in distinguishing the distance of one from the other; they would therefore all seem to be at an equal distance from the spectator.

Each planet is observed to pass through the constellations, Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, and Pisces; and it also appears, that every one has a track peculiar to itself, and that they never move out of a certain space or zone of the heavens, which is called the *zodiac.*

By observing the planets in their periodic revolutions among the fixed stars, it is found, that the paths of the planets are not all in the same plane, but they cross each other in different parts of the heavens. As they thus move in planes that are differently inclined to each other, it became necessary to refer them all to one pláne, in order both to judge more accurately of their inclination, and to avoid the intricacies of calculation; this plane thus became a standard, and was considered as having no obliquity; all the rest are referred thereto. For this purpose astronomers have fixed upon the ecliptic, or orbit of the earth.

The plane of the ecliptic is supposed to divide the celestial sphere into two equal parts, called the *northern and southern celestial hemispheres*; and any body in either of these hemispheres, is said to have north or south latitude, according to the hemisphere it is in. The latitude of a celestial object is its nearest distance from the ecliptic taken on the sphere.

The planets are observed to be sometimes on the northern and sometimes on the southern side of the ecliptic, so that their respective planes cut the ecliptic in two opposite points, called *nodes*; or, in other words, the nodes of a planet's orbit are the two points where it intersects the ecliptic. Thus, let A B C D, *plate* 3, *fig.* 3, represent the ecliptic, B E D F the orbit of a planet, the points, B and D, are the two nodes.

One is called the *ascending node*, and is usually marked thus ☊; it is that through which the planet passes when it moves out of the southern into the northern hemisphere. The other node through which the planet passes in going out of the northern into the southern hemisphere, is called the *descending node*, marked thus ☋.

During therefore every revolution, each planet must describe half its orbit above the plane of the ecliptic, the other half below. They have therefore a north latitude, while they describe one half of their orbit; and a south latitude, while they describe the other half.

The several orbits do not cross the ecliptic at the same point, or with the same angles; their nodes are at different parts of the ecliptic.

A right line joining the two nodes of any planet, is called the *line of the nodes.*

The line of the nodes passes through the sun, for as the motion of every planet is in a plane passing through the sun, consequently, the intersection of these planes, that is, the line of the nodes, must also pass through the sun.

You may render the inclination of the planet's orbits to each other familiar to your mind, by taking as many hoops as there are planets, with a wire thrust through each, and thereby joined to that hoop which represents the ecliptic, and you may then set the other hoops more or less obliquely to the representative of the ecliptic.

I before mentioned to you, that the planets revolved round the sun in orbits nearly circular and concentric, for their several phenomena shew, that they are not strictly so. And astronomers have found, that the only curve they can move in to reconcile all the various appearances is an ellipsis, so that the orbits of the primary planets are ellipses of different curvatures, having one common ſocus in which the sun is fixed; but every secondary planet respects the primary planet, round which it revolves as the ſocus of its elliptic motion.

To describe an ellipsis, let a thread, tied together at both ends, be put over two pins fixed upright upon a plane, at any distance from each other less than the string thus tied will reach, a pen carried round within the string so as to keep it always stretched out with the same tension, will describe upon the plane a curve, which is the periphery or circumference of an ellipsis. Either of the points, S, N, *plate* 3, *fig*. 4, where the pins are fixed in the plane, is called the focus of the ellipsis. The further the foci are from one another, the more oblong will the ellipsis described with the thread be. The nearer the foci are to each other, the nearer will the ellipsis be to a circle.

A line, PA, *plate* 3, *fig*. 4, drawn through the foci both ways till it reaches the circumference, is called the axis, and the greater axis or longest diameter. A point, C, taken in this line equally distant from either of the foci, is called the center of the ellipsis. A line, TV, drawn through the center perpendicular to the longest diameter, till it reaches the circumference both ways, is called the lesser axis, or shortest diameter. The distance between the center and either of the foci, CN or CS, is the excentricity of the ellipsis, which is greater or less, as the ellipsis is more or less oblong.

The orbit of every planet is an ellipsis, having the sun in one of its foci. The axis, PA, of any planet's ellipsis, is called the line of the apsides;

the point A, where the planet is at its greatest distance from the sun, is its *aphelion*, or higher apsis; the point P, where it is at its least distance from the sun, its *perihelion*, or lower apsis; the extreme points of the shortest diameter, TV, are the places of its middle or mean distance from the sun. A line, ST or SV, drawn from either of those points to the sun, is the line of its mean distance. To estimate the excentricity of any planet, we suppose the line of its mean distance, S T, to be divided into 1000 equal parts, and say the excentricity is such a number of those parts.

The motion of the planets in their orbits is not equable; but every planet observes this rule, that a line drawn from the sun to the planet sweeps equal areas upon the plane of its ellipsis in equal times; therefore, every planet moves swiftest in its perihelion, or slowest in its aphelion, with a middle or mean motion at its mean distance.

Thus, in the figure, A is the place of the aphelion, P the place of the perihelion, PA the line of apsides, PA is the transverse diameter of the ellipses, TV the conjugate diameter.

The *mean distance* of a planet from the sun, is its distance from him when the planet is at either extremity of the conjugate diameter, and is equal to half the transverse diameter.

When two planets are seen together in the same sign equally advanced, they are said to be in *conjunction*; but when they are in direct opposite parts of the zodiac, they are said to be in *opposition*.

The place that any planet appears to occupy in the celestial hemisphere, when seen by an observer supposed to be placed in the sun, is called its *heliocentric place*, its *heliocentric latitude*, &c.

The place it occupies when seen from the earth, is called its *geocentric place*, &c.

A motion in the heavens in the order of the signs, as from Aries to Taurus, &c. is said to be *in consequentia*, and such are the real motions of all the planets, though their apparent motions are sometimes contrary, and then they are said to move *in antecedentia*.

The points where the celestial equator cuts the ecliptic are found to have a motion *in antecedentia* of about fifty seconds every year. This change of place of the first point of the ecliptic, from whence the signs are counted, occasions a like change in the signs themselves; which, though scarce sensible for a few years, has now become very considerable. Thus, since the time that astronomy was cultivated by the Greeks, that is, about 2000 years ago, the first point of the ecliptic is removed backward about a whole sign; and though it was then about the middle of the constellation Aries, it is now about the middle of Pisces. Notwithstanding this alteration, the signs still retain their ancient names and marks.

The longitude of a phenomenon in the heavens is the number of degrees counted from the first point of Aries on the ecliptic, to the place where a circle of latitude drawn through the phenomenon would cut the ecliptic at right angles.

Thus, every phenomenon in the heavens is referred to the ecliptic by the circles of latitude, as the longitude of terrestrial places are referred to the equator by the meridians; and whatever sign the circle of latitude passes through, the phenomenon is said to have its place in that sign.

OF THE FIGURE AND LIGHT OF THE PLANETS.

That the sun and planets are spherical bodies, is evident from all the observations that have been made on them; and that the earth is of the same figure, is not only deducible from analogy, but it is also proved by observation, as I shall shew in the process of these Lectures. Astronomers, when they say that the planets are spherical bodies, do not mean a geometrical sphere, but a figure called an *oblate spheroid*, which is something like the figure that a flexible sphere would be formed into by gently pressing it at its poles. Observations have determined this in Jupiter; and it is known that the earth is of this figure, both from observation and actual mensuration.

That the planets are all opake, or dark bodies, and consequently shine only by the light they receive from the sun, is plain, because they are not visible when they are in such parts of their orbits as are between the sun and earth; that is, when their illuminated side is turned from us.

The sun enlightens only half a planet at once; the illuminated hemisphere is always that which is turned towards the sun, the other hemisphere of the planet is dark. To speak with accuracy, the sun being larger than any of the planets, will illuminate rather more than half; but this difference, on account of the great distance of the sun from any of the planets, is so small, that its light may be considered as coming to them in lines physically parallel.

Like other opake bodies, they cast a shadow behind them, which is always opposite to the sun. The line in the planet's body which distinguishes the lucid from the obscure part, appears sometimes straight, sometimes crooked. The convex part of the curve is sometimes towards the splendid, and the concave towards that which is obscure; and *vice versa*, according to the situation of the eye with respect to the planet, and of the sun which enlightens the planet.

OF THE SUN.

The sun is the center of the system, round which the rest of the planets revolve. It is the first and greatest object of astronomical knowledge, and is alone enough to stamp a value on the science to which the study of it belongs. The sun is the parent of the seasons; day and night, summer and winter, are among its surprising effects. All the vegetable creation is the offspring of its beams; our own life is supported by its influence. Nature revives, and puts on a new face, when it approaches nearer to us in spring; and sinks into a temporary death at his departure from us in the winter.

Hence it was with propriety called by the ancients *cor cœli*, the heart of heaven; for, as the heart is the center of the animal system, so is the sun the center of our universe. As the heart is the fountain of the blood, and the center of heat and motion; so is the sun the life and heat of the world, and first mover of the mundane system. When the heart ceases to beat, the circuit of life is at an end; and if the sun should cease to act, a total stagnation would take place throughout the whole frame of nature.

> "By his magnetic beam he gently warms
> The universe, and to each inward part
> With gentle penetration, though unseen,
> Shoots invisible virtue."

The sun is placed near the center of the orbits of all the planets, and turns round his axis in 25¼ days. It is inclined to the ecliptic in an angle of eight degrees. His apparent diameter, at a mean distance from the earth, is about thirty-two minutes twelve seconds.

Those who are not accustomed to astronomical calculation, will be surprized at the real magnitude of this luminary; which, on account of its distance from us, appears to the eye not much larger than the moon, which is only an attendant on our earth. When looking at the sun, you are viewing a globe, whose diameter is about 890,000 English miles; whereas the earth is not more in diameter than 7970 miles: so that the sun is about 1,392,500 times bigger than the earth. As it is the fountain of light and heat to all the planets, so it also far surpasses them in its bulk. In proportion as science has advanced, and more accurate instruments have been made, the magnitude of this luminary has been found to exceed considerably the limits of former calculations.

If the sun were every where equally bright, his rotation on his axis would not be perceptible; but, by means of the spots which are visible on his pure and lucid surface, we are enabled to discover this motion.

When a spherical body is near enough to appear of its true figure, this appearance is owing to the shading upon the different parts of its surface: for, as a flat circular piece of board, when it is properly shaded by painting, will look like a spherical body, so a spherical body appears of its true shape for the same reason that the plane board, in the present instance, appears spherical. But, if the sphere be at a great distance, this difference of shading cannot be discerned by the eye, and consequently the sphere will no longer appear of its true shape; the shading is then lost, and it seems like a flat circle.

It is thus with the sun; it appears to us like a bright flat circle, which flat circle is termed the *sun's disk*. By the assistance of telescopes, dark spots have been observed on this disk, and found to have a motion from east to west: their velocity is greater when they are at the center, than when they are near the limb. They are seen first on the eastern extremity, by degrees they come forwards towards the middle, and so pass on till they reach the western edge, they then disappear; and, after they have lain hid about the same time that they continued visible, they will appear again, as at first. By this motion we discover not only the time the sun employs in turning round its axis, but also the inclination of its axis to the plane of the ecliptic.*

The page of history informs us, that there have been periods when the sun has wanted of its accustomed brightness, and shone with a dim and obscure light for the space of a whole year. This obscurity has been supposed to arise from his surface being at those times covered with spots. Spots have been seen that were much larger than the earth.

The sun is supposed to have an atmosphere round it, which occasions that appearance which is termed the *zodiacal light*. This light is seen at some seasons of the year, either a little after sun-set, or a little before sun-rise. It is faintly bright, and of a whitish colour, resembling the milky way. In the morning it becomes brighter and larger, as it rises above the horizon, till the approach of day, which diminishes its splendor, and renders it at last invisible. Its figure is that of a flat or lenticular spheroid seen in profile. The direction of its longer axis coincides with the plane of the sun's equator. But its length is subject to great variation, so that the distance of its summit from the sun varies from

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* The observer may view the spots of the sun with a refracting telescope of two or three feet, or a reflecting one of twelve inches, eighteen inches, or two feet, taking care to guard the eye with a dark glass, to take off the glaring light; or the image or picture of the sun, with his spots, may be thrown into a dark room through a telescope, and received upon a piece of paper placed nearer or further from the glass at pleasure.

45 to 120 degrees. It is seen to the best advantage about the solstices. It was first described and named by *Cassini*, in 1683; it was noticed by Mr. *Childrey*, about the year 1650.*

OF THE INFERIOR PLANETS, MERCURY AND VENUS.

OF MERCURY. ☿

Of all the planets, Mercury is the least; at the same time it is that which is nearest the sun. It is from his proximity to this globe of light, that he is so seldom within the sphere of our observation, being lost in the splendor of the solar brightness, yet it emits a very bright white light. It is oftener seen in those parts of the world, which are more southward than that which we inhabit; and oftener to us, than to those who live nearer the north pole; for, the more oblique the sphere is, the less is the planet's elevation above the horizon.

Mercury never appears but a few degrees from the sun. The measure of a planet's separation or distance from the sun, is called its *elongation.* His greatest elongation is little more than twenty-eight degrees, or about as far as the moon appears to be from the sun, the second day after new moon. In some of its revolutions, the elongation is not more than eighteen degrees.

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* In the Philosophical Transactions for 1795, is given a paper by Dr. *Herschel* on the physical construction of the sun; which he supposes to have an atmosphere somewhat like that of the earth: the black spots to be the opake ground or body of the sun, and the luminous part the atmosphere, which, when interrupted, gives a transient glimpse of the sun: to be most probably inhabited like the rest of the planets; and, in an answer to the objection, that the heat of the sun renders it unfit for habitation, "that heat is produced by the sun's rays, only when they act on a calorific medium," and "that they are the cause of the production of heat by uniting with the matter of fire contained in the substances heated." For further particulars of this curious hypothesis, I refer the reader to the Transactions. Edit.

Mercury is computed to be at about 37 millions of miles from the sun, and to revolve round him in 87 days, 23 hours, and nearly 16 minutes, which is the measure of its year, about one-fourth of ours. As, from the nearness of this planet to the sun, we neither know the time it revolves round its axis, nor the inclination of that axis to the plane of its orbit, we are necessarily ignorant of the length of its day and night, or the variety of seasons it may be liable to. Mercury is 3000 miles in diameter, and therefore contains in surface 28,274,400 square miles. Large as Mercury, when thus considered, appears to be, it is but an atom, when compared with Jupiter, whose diameter is 90,000 miles. Its apparent diameter, at a mean distance from the earth, is 20 seconds.

Mercury is supposed to move at the rate of 110,680 miles per hour. The sun is above 26,000,000 times as big as Mercury; so that it would appear to the inhabitants of Mercury nearly three times larger than it does to us; and its disk, or face, about seven times the size we see it. As the other five planets are above Mercury, their phenomena will be nearly the same to it as to us. Venus and the Earth, when in opposition to the sun, will shine with full orbs, and afford a brilliant appearance to the Mercurian spectator.

Mercury, like the moon, changes its phases, according to its several positions, with respect to the sun and earth. He never appears quite round or full to us, because his enlightened side is never turned directly towards us, except when he is so near the sun, as to become invisible. The times for making the most favourable observations on this planet, are, when it passes before the sun, and is seen traversing his disk, in the form of a black spot. This passage of a planet over the face of the sun, is called a *transit*. It happens in its lower conjunction, at a particular situation of the nodes.

If Mercury, at his inferior conjunction, comes to either of his nodes about these times, he will appear to transit over the disk of the sun. But in all other parts of his orbit his conjunctions are invisible, because he either goes above or below the sun.

OF VENUS. ♀

Venus is the brighest and largest, to appearance, of all the planets, distinguished from them all by a superiority of lustre: her light is of a white colour, and so considerable, that in a dusky place she projects a sensible shade.

The diameter of Venus is 7,699 English miles; her distance from the sun is about 69,500,000 miles; she goes round the sun in 224 days, 6 hours, 49 minutes, moving at the rate of 80,955 miles per hour. Her motion round her axis has been fixed by some at 23 hours, 22 minutes; by others at about 24 days. She, like Mercury, constantly attends the sun, never departing from him above 47 or 48 degrees. Like Mercury, she is never seen at midnight, or in opposition to the sun, being visible only for three or four hours in the morning or evening, according as she is before or after the sun.

One would not imagine that this planet, which appears so much superior to Saturn in the heavens, is so inconsiderable when compared to it; for the diameter of Saturn is 79,979 miles; while, on the other hand, one would scarce imagine, that Venus, which appears but as a lucid spangle in the heavens, was so large a globe as she truly is, her diameter being 7,699 miles. It is the distance which produces these effects; which gives and takes away the magnitude of things. Her apparent size varies with her distance; at some seasons she appears nearly 32 times larger than at others.

When this planet is in that part of its orbit which is west of the sun, that is, from her inferior to her superior conjunction, she rises before him in the morning, and is called *Phosphorus*, or *Lucifer*, or the *Morning Star.* When she appears east of the sun, that is, from her superior to her inferior conjunction, she sets in the evening after him; or, in other words, shines in the evening after he sets, and is called *Hesperus*, or *Vesper*, or the *Evening Star.*

The inhabitants of Venus will see the planet Mercury always accompanying the sun; and he will be to them, by turns, an evening or a morning star, as Venus is to us. To the same inhabitants, the sun will appear almost twice as large as he does to us.

Venus, when viewed through a telescope, is seldom seen to shine with a full face; but has phases, just like the moon, from the fine thin crescent to the enlightened hemisphere. Her illuminated part is constantly turned towards the sun; hence its horns are turned towards the east when it is a morning star, and towards the west when it is an evening star. Some astronomers have thought they perceived a satellite moving round Venus; but as succeeding observers have not been able to verify their observations, they are supposed to have originated in error. In observing the transit of Venus, Mr. *Dunn*, and other gentlemen, saw a penumbra which took place about five seconds before the contact, preceding the egress of the planet; and from thence they concluded, that it had an atmosphere of about 50 geographical miles in height.*

We are told, that when *Copernicus* first published his account of the solar system, it was objected to him that it could not be true, because if it was, the inferior planets must have different phases, according to their different situation with respect to the sun and earth: whereas they always appear round to us. The answer, said to be made by him, is, that they appear round to the eye by reason of their distance; but if we could have a nearer, or more distinct view of them, we should see in them the same phases we do in the moon. The invention of telescopes is said to have verified this prediction of *Copernicus*. But it is neither probable, that a defender of the Ptolemaic system should make such an objection, or *Copernicus* such an answer; since in the Ptolemaic, as well as in the Copernican system, the shape of these planets ought to change just as the moon does; consequently, the mere change of shape in the inferior planets is an argument which, in the common way of urging it, proves nothing at all as to the truth or falshood of the Copernican system. If, besides the changes of shape made in the inferior planets, we consider the situation of the planets with respect to the sun, when these changes happen; this, indeed, will shew us, that the Ptolemaic system is false, as will be seen in a subsequent part of these Lectures.

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* From some late observations of Dr. *Herschel* and Mr. *Schroeter*, it appears that Venus has an atmosphere of considerable height and density, and that it has also inequalities on its surface like those of other planets. Edit.

Taking the times in which the planets move round the sun, for the length of their year; and the times of their turning round their axes, for the length of their days and nights together; and assuming, as true, the observations of *Bianchini*, relative to the rotation of Venus round her axis; we may say, that a day and a night in Venus is as long as 23½ days and nights with us; her axis inclines 75 degrees from the axis of her orbit, on which account the length of her days and nights differs much more in proportion, and the variations of her seasons are greater than those of our earth. She very seldom has the forenoon and afternoon of the same day an equal length. At her equator she has the four seasons twice every year, with other peculiarities, which are enumerated in larger treatises on this subject.

Venus is sometimes seen passing over the disk of the sun, as a round dark spot. These appearances, which are called transits, happen very seldom; though there have been two within these few years, the one in June, 1761, the other in June, 1769; the next will be in the year 1874.

OF THE EARTH. ⊕

The next planet that comes before us is the Earth that we inhabit; small as it really is compared to some of the other planets, it is to us of the highest importance: we wish only to attain knowledge of others, that we may find out their relation to this, and from thence learn our connexion with the universe at large. But when viewed with an eye to eternity, its value to us is heightened in a manner that exceeds expression, and surpasses all the powers of the human mind. He alone can form some idea of it, who, in the regions of celestial bliss, is become a partaker of the length, and breadth, the depth and height, of divine love.

The orbit of the Earth is placed between those of Venus and Mars. The diameter of the Earth is 7920 miles; its distance from the sun is nearly 96 millions of miles, and it goes round him in a year, moving at the rate of 68,856 miles per hour. Its apparent diameter, as seen from the sun, is about twenty-one seconds.

It turns round its axis, from west to east, in twenty-four hours, which occasions the apparent diurnal motion of the sun, and all the heavenly bodies round it, from east to west, in the same time; it is, of course, the cause of their rising and setting, of day and night.

The axis of the Earth is inclined 23½ degrees to the plane of its orbit, and keeps in a direction parallel to itself, throughout its annual course, which causes the return of spring and summer, autumn and winter. Thus its diurnal motion gives us the grateful vicissitude of night and day, and its annual motion the regular succession of seasons.

OF THE MOON. ☾

Next to the sun, the Moon is the most splendid and shining globe in the heavens, the satellite, or inseparable companion of the earth. By dissipating, in some measure, the darkness and horrors of the night; subdividing the year into months; and regulating the flux and reflux of the sea; she not only becomes a pleasing, but a welcome object; an object affording much for speculation to the contemplative mind, of real use to the navigator, the traveller, and the husbandman. The Hebrews, the Greeks, the Romans, and, in general, all the ancients used to assemble at the time of New Moon, to discharge the duties of piety and gratitude for its manifold uses.

That the Moon appears so much larger than the other planets, is owing to her vicinity to us; for, to a spectator in the sun, she would be scarcely visible without the assistance of a telescope. Her distance is but small from us, when compared with that of the other heavenly bodies; for among these, the least absolute distance, when put down in numbers, will appear great, and the smallest magnitude immense.

The Moon is 2161 miles in diameter; her bulk is about three-elevenths of the earth; her distance from the center of the earth 240,000 miles; she goes round her orbit in 27 days, 7 hours, 43 minutes, moving at the rate of 2299 miles per hour. The time in going round the earth, reckoning from change to change, is 29 days, 12 hours, 44 minutes. Her apparent diameter, at a mean distance from the earth, is 31 minutes 16 seconds; but as viewed from the sun, at a mean distance about 6 seconds.

Her orbit is inclined to the ecliptic, in an angle of 5 degrees, 18 minutes, cutting it in two points, which are diametrically opposite to each other; these points are called her nodes. The nodes have a motion westward, or contrary to the order of the signs, making a complete revolution in about 19 years; in which time, each node returns to that point of the ecliptic whence it before receded.

If the Moon where a body possessing native light, we should not perceive any diversity of appearance; but as she shines entirely by light received from the sun, and reflected from her surface, it follows, that according to the situation of the beholder with respect to the illuminated part, he will see more or less of her reflected beams; for only one half of a globe can be enlightened at once.

Hence, while she is making her revolution round the heavens, she undergoes great changes in her appearance. She is sometimes on our meridian at midnight, and therefore in that part of the heavens which is opposite to the sun; in this situation she appears as a complete circle, and it is said to be Full Moon. As she moves eastward, she becomes deficient on the west side, and in about 7½ days comes to the meridian, at about six in the morning, having the appearance of a semicircle, with the convex side turned towards the sun; in this state, her appearance is called the Half Moon. Moving on still eastward, she becomes more deficient on the west, and has the form of a crescent, with the convex side turned towards the sun; this crescent becomes continually more slender, till about fourteen days after the Full Moon she is so near the sun, that she cannot be seen, on account of his great splendor. About four days after this disappearance, she is seen in the evening, a little eastward of the sun, in the form of a fine crescent, with the convex side turned from the sun; moving still to the eastward, the crescent becomes more full; and when the moon comes to the meridian, about six in the evening, she has again the appearance of a bright semicircle; advancing still to the eastward, she becomes fuller on the east side; at last, in about 29½ days, she is again opposite to the sun, and again full.

It frequently happens, that the Moon is eclipsed when at the full; and that the sun is eclipsed some time between the disappearance of the Moon in the morning on the west side of the sun, and her appearance in the evening on the east side of the sun. The nature of these phenomena will be more considered, when we come to treat particularly of eclipses.

In every revolution of the Moon about the earth, she turns once round upon her axis, and therefore always presents the same face to our view; and as, during her course round the earth, the sun enlightens successively every part of her globe only once, consequently, she has but one day in all that time, and her day and night together are as long as our lunar month. As we see only one side of the moon, we are therefore invisible to the inhabitants on the opposite side, without they take a journey to that side which is next to us, for which purpose some of them must travel more than 1500 miles.

As the Moon illuminates the earth by a light reflected from the sun, she is reciprocally enlightened, but in a much greater degree, by the earth; for the surface is above thirteen times greater than that of the moon; and therefore, supposing their power of reflecting light to be equal, the earth will reflect thirteen times more light on the moon than she receives from it. When it is what we call new Moon, we shall appear as a Full Moon to the Lunarians; as it increases in light to us, ours will decrease to them: in a word, our earth will exhibit to them the same phases as she does to us.

We have already observed, that from one half of the Moon the earth is never seen; from the middle of the other half, it is always seen over head, turning round almost thirty times as quick as the Moon does. To her inhabitants, the earth seems to be the largest body in the universe, about thirteen times as large to them as she does to us. As the earth turns round its axis, the several continents and islands appear to the Lunarians as so many spots, of different forms; by these spots, they may determine the time of the earth's diurnal motion; by these spots, they may, perhaps measure their time; they cannot have a better dial.

OF THE SUPERIOR PLANETS.

Mars, Jupiter, Saturn, and the Georgium Sidus, are called superior planets, because they are higher in the system, or farther from the center of it, than the earth is.

They exhibit several phenomena, which are very different from those of Mercury and Venus; among other things, they come to our meridian both at noon and midnight, and are never seen crossing the sun's disk.

OF MARS, ♂

Mars is the least bright and elegant of all the planets; its orbit lies between that of the Earth and Jupiter, but very distant from both. He appears of a dusky reddish hue; from the dullness of his appearance, many have conjectured, that he is encompassed with a thick cloudy atmosphere; his light is not near so bright as that of Venus, though he is sometimes nearly equal to her in size.

Mars, which appears so inconsiderable in the heavens, is 5,309 miles in diameter. Its distance from the sun is about 146,000,000 miles. It goes round the sun in 1 year, 321 days, 23 hours, moving at the rate of 55,287 miles per hour. It revolves round its axis in 24 hours, 39 minutes. To an inhabitant in Mars, the sun would appear one third less in diameter than it does to us. Its apparent diameter, as viewed at a mean distance from the earth, ia 30 seconds.

Mars, when in opposition to the sun, is five times nearer to us than when in conjuction. This has a very visible effect on the appearance of the planet, causing him to appear much larger at some periods than at others.

The analogy between Mars and the Earth is by far the greatest in the whole solar system; their diurnal motion is nearly the same; the obliquities of their respective ecliptics not very different. Of all the superior planets, that of Mars is by far the nearest like the Earth: nor will the Martial year appear so dissimilar to ours, when we compare it with the long duration of the years of Jupiter, Saturn, and the Georgium Sidus. It probably has a considerable atmosphere; for, besides the permanent spots on its surface, Dr. *Herschel* has often perceived occasional changes of partial bright belts, and also once a darkish one in a pretty high latitude; alterations which we can attribute to no other cause than the variable disposition of clouds and vapours floating in the atmosphere of the planet.

A spectator in Mars will rarely, if ever, see Mercury, except when they see it passing over the sun's disk. Venus will appear to him about the same distance from the sun, as Mercury appears to us. The Earth will appear about the size of Venus, and never above 48 degrees from the sun; and will be, by turns, a morning and evening star to the inhabitants of Mars. It appears, from the most accurate observations, that Mars is a spheroid, or flatted sphere, the equatoreal diameter to the polar being in the proportion of about 131 to 127; and there is reason to suppose, that all the planets are of this figure.

OF JUPITER. ♃

Jupiter is situated still higher in the system, revolving round the sun, between Mars and Saturn. It is the largest of all the planets, and easily distinguished from them by his peculiar magnitude and light. To the naked eye it appears almost as large as Venus, but not altogether so bright.

Jupiter revolves round its axis in 9 hours, 56 minutes; its revolution in its orbit to the same point of the ecliptic is 11 years, 314 days, 10 hours. The disproportion of Jupiter to the Earth, in size, is very great; viewing him in the heavens, we consider him as small in magnitude; whereas he is in reality 90,228 miles in diameter. His distance from the sun is 499,750,000 miles; he moves at the rate of rather more than 29,083 miles per hour. His apparent diameter, as seen at a mean distance from the earth, is 39 seconds.

To an eye placed in Jupiter, the sun would not be a fifth part of the size he appears to us, and his disk be 25 times less. Though Jupiter be the largest of all the planets, yet his revolution round his axis is the swiftest. The polar axis is shorter than the equatorial one, and his axis perpendicular to the plane of his orbit.

Jupiter, when in opposition to the sun, is much nearer the earth, than when he is in conjunction with him; at those times he appears also larger, and more luminous than at other times.

In Jupiter, the days and nights are of an equal length, each being about five hours long. We have already observed, that the axis of his diurnal rotation is nearly at right angles to the plane of his annual one, and consequently there can be scarce any difference in seasons; and here, as far as we may reason from analogy, we may discover the footsteps of wisdom; for, if the axis of this planet were inclined by any considerable number of degrees, just so many degrees round each pole would, in their turn, be almost six years in darkness; and, as Jupiter is of such an amazing size, in this case immense regions of land would be uninhabitable.

Jupiter is attended by four satellites, or moons; these are invisible to the naked eye, but through a telescope they make a beautiful appearance. As our moon turns round the earth, enlightening the nights by reflecting the light she receives from the sun, so these also enlighten the nights of Jupiter, and move round him in different periods of time, proportioned to their several distances: and as the moon keeps company with the earth in its annual revolution round the sun; so these accompany Jupiter in his course round that luminary.

In speaking of the satellites, we distinguish them according to their places, into the first, the second, and so on; by the first, we mean that which is nearest to the planet.

The outermost of Jupiter's satellites will appear almost as big as the moon does to us; five times the diameter, and twenty-five times the disk of the sun. The four satellites must afford a pleasing spectacle to the inhabitants of Jupiter; for sometimes they will rise all together, sometimes be all together on the meridian, ranged one under another, besides frequent eclipses. Notwithstanding the distance of Jupiter and his satellites from us, the eclipses thereof are of considerable use for ascertaining with accuracy the longitude of places. From the four satellites the inhabitants of Jupiter will have four different kinds of months, and the number of them in their year not less than 4,500.

An astronomer in Jupiter will never see Mercury, Venus, the Earth, or Mars; because, from the immense distance at which he is placed, they must appear to accompany the sun, and rise and set with him; but then he will have for the objects of his observation, his own four moons, Saturn, his ring and satellites, and probably the Georgium Sidus.

OF SATURN. ♄

Before the discovery of the Georgium Sidus, Saturn was reckoned the most remote planet in our system; he shines but with a pale feeble light, less bright than Jupiter, though less ruddy than Mars. The uninformed eye imagines not, when it is directed to this little speck of light, that it is viewing a large and glorious globe, one of the most stupendous of the planets, whose diameter is 79,979 miles. We need not, however, be surprised at the vast bulk of Saturn, and its disproportion to its appearance in the heavens; for we are to consider that all objects decrease in their apparent magnitude, in proportion to their distance: but the distance of Saturn is immense; that of the earth from the sun is 96,000,000 miles, of Saturn 916,500,000 miles!

The length of a planet's year, or the time of its revolution round its orbit, is proportioned to its distance from the sun. Saturn goes round the sun in 29 years, 167 days, 6 hours, moving at the rate of rather more than 22,298 miles per hour. His apparent diameter at a mean distance from the earth is 16 seconds.

It has not yet been ascertained by astronomical observation, whether Saturn revolves or not upon his axis: we are therefore ignorant of the length of his day and of his night. The sun's disk will appear ninety times less to an inhabitant of Saturn than it does to us; but, notwithstanding the sun appears so small to the inhabitants of the regions of Jupiter and Saturn, the light that he will afford them is much more than would be at first supposed; and calculations have been made from which it is inferred, that the sun will afford 500 times as much light to Saturn as the full moon to us; and 1600 times as much to Jupiter. To eyes like ours, unassisted by instruments, Jupiter and the Georgium Sidus would be the only planets seen from Saturn, to whom Jupiter would sometimes be a morning, sometimes an evening star.

One of the first discoveries of the telescope, when brought to a tolerable degree of perfection, was, that Saturn did not appear like other planets. *Galileo*, in 1610, supposed it composed of three stars or globes, a larger in the middle, and a smaller on each side; and he continued his observations till the two lesser stars disappeared, and this planet looked like the others. Further observation shewed, that what *Galileo* took for two stars, were parts of a ring. This singular and curious appendage to the planet Saturn, is a thin, broad, opake ring, encompassing the body of the planet, without touching it, like the horizon of an artificial globe, appearing double when viewed through a good telescope. The space between the ring and the globe of Saturn is supposed to be rather more than the breadth of the ring; the plane of the ring is inclined to the plane of the ecliptic, in an angle of 30 degrees, and is about 21,000 miles in breadth. It puts on different appearances to us, sometimes being seen quite open, at others, only as a line upon the equator. It is probable, that it at times casts a shadow over vast regions of Saturn's body. This ring suspended round the body of the planet, and keeping its place without any connexion with the body, is quite different from all other planetary phenomena with which we are acquainted. But this is rendered still more surprising by the discoveries of Dr. *Herschel*, who finds that the planet Saturn has two concentric rings, of unequal dimensions and breadth situated in one plane, which is probably not much inclined to the equator of the planet. These rings are at a considerable distance from each other, the smallest being much less in diameter at the outside, than the largest is at the inside; the two rings are entirely detached from each other, so as plainly to permit the open heavens to be seen through the vacancy between them. Of the nature of this ring, various and uncertain were the conjectures of the first observers; though not more perplexed than those of the latest. Of its use to the inhabitants of Saturn, we are as ignorant as of its nature.

Saturn is not only furnished with this beautiful ring, but it has also seven attendant moons, the two first next his body were lately discovered by Dr. *Herschel*.

OF THE GEORGIUM SIDUS. ♅

From the time of *Huygens* and *Cassini*, to the discovery of the Georgium Sidus by Dr. *Herschel*, though the intervening space was long, though the number of astronomers was increased, though assiduity in observing was assisted by accuracy and perfection in the instruments of observation, yet no new discovery was made in the heavens, the boundaries of our system were not enlarged. The inquisitive mind naturally inquires, why, when the number of those that cultivated the science was increased, when the science itself was so much improved, in practical discoveries it was so deficient? A small knowledge of the human mind will answer the question, and obviate the difficulty. The mind of man has a natural propensity to indolence; the ardour of its pursuits, when they are unconnected with selfish views, is soon abated, small difficulties discourage, little inconveniences fatigue it, and reason soon finds excuses to justify, and even applaud this weakness. In the present instance, the unmanageable length of the telescopes that were in use, and the continual exposure to the cold air of the night, were the difficulties the astronomer had to encounter with; and he soon persuaded himself, that the same effects would be produced by shorter telescopes, with equal magnifying power; herein was his mistake, and hence the reason why so few discoveries have been made since the time of *Cassini*. A similar instance of the retrogradation of science occurs in the history of the microscope, as I have shewn in my Essays on that instrument.

The Georgium Sidus was discovered by Dr. *Herschel*, in the year 1781; for this discovery, he obtained from the Royal Society the honorary recompence of Sir *Godfrey Copley*'s medal. He named the planet in honour of his Majesty King George III. the patron of science, who has taken Dr. *Herschel* under his patronage, and granted him an annual salary. By this munificence he has given scope to a very uncommon genius, and enabled him to prosecute his favourite studies with unremitted ardour.

In so recent a discovery of a planet so distant, many particulars cannot be expected. Its year is supposed to be more than 80 years; its diameter 34,299 miles; distance from the sun about 1,832 millions of miles; the inclination of its orbit 43 degrees 35 seconds; its diameter, compared to that of the earth, as 431,769 to 1; in bulk it is 8,049,256 times as large as the earth. Its light is of a bluish white colour, and its brilliancy between that of the Moon and Venus.

Though the Georgium Sidus was not known as a planet till the time of Dr. *Herschel*, yet there are many reasons to suppose it had been seen before, but had then been considered as a fixed star. Dr. *Herschel*'s attention was first engaged by the steadiness of its light; this induced him to apply higher magnifying powers to his telescope, which increased the diameter of it: in two days he observed that its place was changed; he then concluded it was a comet; but in a little time he with others determined that it was a planet, from its vicinity to the ecliptic, the direction of its motion, being stationary in the time, and in such circumstances as correspond with similar appearances in other planets.

With a telescope which magnifies about 300 times, it appears to have a very well-defined visible disk; but, with instruments of a smaller power it can hardly be distinguished from a fixed star between the sixth and seventh magnitude. When the moon is absent, it may also be seen by the naked eye.

Dr. *Herschel* has since discovered, that it is attended by two satellites: a discovery which gave him considerable pleasure, as the little secondary planets seemed to give a dignity to the primary one, and raise it into a more conspicuous situation among the great bodies of our solar system.*

As the distances of the planets, when marked in miles, are a burden to the memory, astronomers often express their mean distances in a shorter way, by supposing the distance of the earth from the sun to be divided into ten parts. Mercury may then be estimated at four of such parts from the sun, Venus at seven, the Earth at ten, Mars at fifteen, Jupiter at fifty-two such parts, Saturn at ninety-five, and the Georgium Sidus 190 parts.

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* Four additional satellites to this planet have been discovered by Dr. *Herschel*, so that it appears, that it now has six. The planes of their orbits form such large angles with that of the planet, and consequently the ecliptic, as to be almost perpendicular to it; and another more singular dissimilarity to that of the old planets is, that they move in a retrograde direction. For further particulars, see Philos. Trans. 1798, p. 47. Edit.

TABLES OF THE DIAMETERS, DISTANCES, &c. OF THE PLANETS.

Accompanied with various comparisons in order to render the ideas of these distances, &c. clearer to the mind.

When you endeavour to form any idea of distance, magnitude, or duration, by numbers only, you soon exceed the limits of conception, and find your faculties of reasoning as finite as your senses. Hence astronomers are frequently obliged to have recourse to mixed ideas, and make things of different natures and properties assist each other, to excite more adequate ideas of what they would have expressed. Some of these methods I shall now lay before you, to assist your imagination in forming its ideas of the vast distances and sizes of the planets.

	Diameters in English miles.	In diam. of the earth.	Proportion of surface with respect to the earth.	Proportion of bulk with respect to the earth.
Sun......	893,522	113	12,719	1,434,400
Mercury..	3,261	$\frac{2}{5}$	$\frac{1}{6}$	$\frac{1}{14}$
Venus....	7,699	$\frac{32}{33}$	near 1	$\frac{9}{10}$
Earth	7,920	1	1	1
Moon	2,161	$\frac{3}{11}$	above $\frac{1}{13}$	$\frac{1}{56}$
Mars.....	5,312	$\frac{2}{3}$	$\frac{4}{9}$	$\frac{3}{16}$
Jupiter...	90,255	11 $\frac{1}{3}$	129 $\frac{3}{4}$	1,479
Saturn ...	80,012	10	102	1,030
Georgium Sidus	34,217	4 $\frac{1}{3}$	18 $\frac{3}{4}$	81 $\frac{1}{6}$

MEAN DISTANCES IN MILLIONS OF MILES.

The distances being very great, the nearest million only is inserted, that it may be easier remembered.

Distances from the sun.	Millions of miles.	Difference between the greatest and least distance of the sun from the earth, in millions of miles.
Sun......		3
Mercury..	$37\frac{1}{5}$	$74\frac{4}{15}$
Venus....	$69\frac{1}{2}$	139
Earth....	96	0
Moon....	96	33,570 miles.
		Millions.
Mars....	$146\frac{1}{3}$	192
Jupiter...	$499\frac{3}{4}$	192
Saturn...	$916\frac{1}{2}$	192
Georgium Sidus.	1,832	192

PERIODS ROUND THE SUN ACCORDING TO OUR YEARS AND MONTHS.

	years.	days.	hours.	min.	sec.	Progressive motion in their orbit, miles per hour.
Mercury..	—	87	23	15	37	110,680
Venus....	—	224	16	49	12	80,955
Earth....	—	365	5	48	45	68,856
Mars....	—	686	23	30	63	55,783
Jupiter...	11	314	12	—	—	30,193
Saturn...	29	167	5	—	—	22,298
Georgium Sidus	80	—	—	—	—	16,411

	days.	hours.	min.	
Moon's periodical revolution round the earth	27	7	43	2,299
Synodical revolv. or from change to change	29	12	44	

The following TABLE from Mr. *Vince*'s Plan of a Course of Lectures, may be considered as more accurate; it is deduced from M. *de la Lande*'s work.

	mean dist.	Sid. Rev.				Nod. in 1750				Incl. 1786.			Aphelia 1750.			
		d.	h.	′	″	s.	°	′	″	°	′	″	s.	°	′	″
Mercury ...	38710	87	23	15	14	1	15	20	43	7	0	0	8	13	33	58
Venus	72333	224	16	49	11	2	14	26	18	3	23	35	10	7	46	42
Earth	100000	365	6	9	12								3	8	39	34
Mars	152369	686	23	30	36	1	17	38	38	1	51	0	5	1	28	14
Jupiter	520279	4332	14	27	11	3	7	55	32	1	18	56	6	10	21	4
Saturn	954072	10759	1	51	11	3	21	32	22	2	29	50	8	28	9	7
Geor. Sidus	1,908180	83yr. 157d. 18h.				3	12	33	31	0	46	20	11	17	6	44

	Revolution on its own axis according to our days.				Motion on its axis, miles per hour.
	days.	hours.	min.	sec.	
Sun	25	6			3,957
Mercury ..	unknown.				unknown.
Venus		23	22		1,065
Earth		23	56	4	1,042
Mars		24	39		556
Jupiter ...		9	56		25,920.
Saturn ...	unknown.				unknown.
Georgium Sidus	unknown.				unknown.
Moon	27	7	43		near 10½

The rotation of Saturn, agreeable to Dr. *Usher*'s computations, is 10 hours, 12½ minutes. A different result was however obtained, by taking the density of Saturn, as stated by M. *de la Lande*. Dr. *Herschel* has settled the rotation of Saturn's ring at 10 hours, 32 minutes, 16 seconds.

	Light and heat in proportion to what the earth receives.	Appearances of the sun in proportion to what it appears on the earth.
Mercury	7 times more	7 times greater
Venus	double	twice as great
Earth	1	1
Mars	half	half as big
Jupiter	one 27th	one 27th
Saturn	one 91	one 91
Georg. Sidus..	one 364th	one 364th
Moon	1	1

Sun's apparent diameter, 1 min. 41 sec.

DISTANCES AND APPARENT DIAMETERS OF THE SUN AND PLANETS.

	Distances from the earth.			Apparent diameter viewed from the earth.		
	Greatest. mill. of miles	Least. mill. of miles	Mean. mill. of miles	Greatest	Least.	Mean.
				′ ″	′ ″	′ ″
Sun	97 ½	94 ½	96	32 38	31 34	32 5
Mercury .	133 ⅕	58 ⅘	96	0 11	0 5	0 7
Venus ..	165 ½	26 ½	96	1 0	0 10	0 17
Earth ...	0	0	0	0 0	0 0	0 0
Mars....	242 ⅓	50 ⅓	146 ⅓	0 22	0 4	0 7
Jupiter ..	595 ¾	403 ¾	499 ¾	0 46	0 31	0 37
Saturn ..	1.012 ½	820 ½	916 ½	0 18	0 14	0 37
Georg. Sid.	1.928	1736	1832	0.3.9	0 3.9	0 16
	miles.	miles.	miles.			3.9
Moon ...	256.785	223.211	240.000	33.36	28.55.30	31 15

It has been found that a cannon-ball moves about 8 miles in one minute, 704 feet in a second; and that sound moves about 13 miles in one minute, 1144 feet in a second.

A very high wind may make sound move one mile in 4,4 seconds, that is, in about one-twentieth less time than in calm weather.

The most violent storm does not move above one mile in a minute, 88 feet in a second.

From hence it has been computed, that a body issuing from the sun with the swiftness of a cannon-ball, that is, eight miles in a minute, would employ the following time in reaching

	years	months	days	hours	min.
Mercury	8	10	6	13	18
Venus	16	6	8	20	58
Earth	22	10	4	21	20
Mars	34	9	19	16	35
Jupiter	118	9	8	16	40
Saturn	217	10	2	19	16
Georgium Sidus	435	4	24	0	40
Any fixed star that has been accurately observed	7,600,000				

A ray of light comes from the sun to the earth in 8 min. 13 sec. moves therefore 11,693,462 miles in one minute, 194,891 miles in one second.

A ray of light comes from the moon in 1,23 second.

From the very accurate observations of Dr. *Bradley*, it is inferred, that no fixed star, of the great numbers observed by him, can be at a less distance from the earth than about 400,000 distances of the sun from the earth; so that a ray of light, which comes from the earth in 8 minutes, 13 seconds, issuing from such a star, must require 6 years and 3 months to reach the earth.

The following may therefore be considered as proportionable distances of the celestial bodies from the sun.

Mercury	28 yards.
Venus	52 ditto.
Earth	79 ditto.
Mars	109 ditto.
Jupiter	273 ditto.
Saturn	684 ditto.
Georgium Sidus	1357 miles.

Moon 6½ inches from the earth, Syrius 8410 miles.

PROPORTIONAL MAGNITUDE.

Sun	2 feet in diameter.
Mercury	$\frac{1}{12}$ of an inch.
Venus	$\frac{1}{7}$ of an inch.
Earth	$\frac{1}{5}$ $\frac{1}{100}$.
Mars	$\frac{1}{15}$ of an inch.
Jupiter	$2\frac{3}{4}$ inches.
Saturn	$2\frac{1}{10}$ inches.
Georgium Sidus	about 1 inch.

The distance of Syrius is 18,717,442,690,526 miles. A cannon-ball going at the rate of 19.05 miles per minute, would only reach it in about 1,868,307 years, 88 days, 24 hours. The circumference of its orbit is 117,605,162,638,454; if the star moved through this space in 24 hours, it must go 361,170,863¾ miles per second.

Such is the immense distance even of a star of the first magnitude, that, supposing the world to have existed 6000 years, and the distance to be reduced to 311⅓, or 311.333 inches, or 25 feet 11 inches, then a cannon-ball, going at the rate of 1143 miles per hour, and set in motion at the creation of the world, would now have passed only *one* inch of that reduced space; because one inch bears the same proportion to 311.3 as the distance which the ball would go in 6000 years does to the whole distance of the star. So,

If a cannon-ball goes 1 inch in 6000 years, how far will it go in 1,868,307?—*Answer*, 311.333, or 25 feet, 11 inches. Or, If a cannon-ball goes 18,717,442,690,526 miles in 1,868,307 years, how far will it go in 6000?—*Ans.* 60,110,386,645, which number is to 18717, &c. as 1 inch is to 311.333.

By the same rule, if we suppose a star of the second, third, tenth, one-hundredth magnitude, its distance will be proportionably great, and the space gone through proportiônably small; that is, in the same time the ball would have gone only one-half, one-third, one-tenth, one-hundredth, &c. of an inch. With respect to a star of the third magnitude, it would have passed through a space equal to one barley-corn; with respect to one of the four-hundredth, not the space corresponding to one hair's breadth, reckoning 400 hairs equal to one inch.

This supposes that a star of the third, tenth, four-hundredth, &c. magnitude, is 3, 10, 400 times as distant as one of the first; and we may also suppose that a star, which cannot be seen but with a power of 100, 1000, &c. is 100 and 1000 times more distant than one which the naked eye can just discover.

The distance of a star of the second magnitude is 37,434,885,381,053½ miles; the diameter of its orbit equal to 74,869,770,762,107.

The circumference of its orbit is equal to 235,210,325,276,908.7; a degree of this is 653,362,014,658; a minute, 10,889,366,910.75; a second, 181,489,448½. A cannon-ball would require 65216 years, 86 days, 6 hour, 17 minutes, 13 seconds, to go through one degree of this orbit; 1086 years, 342 days, 2 hours, 30 minutes, 17 seconds, to pass through one minute; and 18 years, 42 days, 4 hours, 50 minutes, 30 seconds, to go over one second of it.

The distance between the stars marked δ and ϵ in Orion's belt, is 1 degree, 23 minutes, 12 seconds.

	°	′	″
Between ε and ζ - - - - - -	1	21	9
Between δ and ζ - - - - - -	2	44	21

Now taking the whole years, and neglecting the fractions of the above numbers 652161086, &c. 18; a cannon-ball would be 90410 years in passing from δ to ε, 88184 in going from ε to ζ, and 178594 from δ to ζ.

So likewise the distance between α and β, *Ursa Major*, or the two hind wheels of the *Placestrum*, is 5° 23′ 20″, which a cannon-ball would require 351418 years to pass over.

This evidently supposes, that all stars of equal magnitude are equally distant (not that this is certain, or even probable; but some data must be assumed); and though not accurate, equally shew the wonders of creation.

The diameter of the earth being 7920 miles, the surface in round numbers may be called 200 millions of square miles.

		Millions.
The surface - - -		200
Whereof the sea occupies - -	$\frac{4}{5}$	160
The land - - -	$\frac{1}{5}$	40

Of that 40, America is 14, about $\frac{1}{3}$; Asia 11, about $\frac{1}{4}$; Africa 10, $\frac{1}{4}$; Europe not 5, not $\frac{1}{8}$.

Places of the nodes for 1750.					Annual motion of the nodes.	
	sign.	deg.	min.	sec.	min.	sec.
Mercury	1	15	20	43	7	0
Venus	2	14	26	18	19	2
Mars	1	17	38	38	22	2
Jupiter	3	7	55	32	14	5
Saturn	3	21	32	22	16	9
Georg. Sidus	3	12	33	31		

Inclination of the orbits.

Mercury	7	0	0
Venus	3	23	35
Mars	1	51	0
Jupiter	1	18	56
Saturn	2	19	50
Georgium Sidus	0	46	20

I shall conclude this general survey of the solar system in the words of that excellent mathematician, Mr. *Maclaurin.* The view of nature, which is the immediate object of sense, is very imperfect, and of small extent; but by the assistance of art, and the aid of reason, becomes enlarged, till it loses itself in infinity. As magnitude of every sort, abstractedly considered, is capable of being increased to infinity, and is also divisible without end; so we find, that in nature the limits of the greatest and least dimensions of things are actually placed at an immense distance from each other.

" We can perceive no bounds of the vast expanse, in which natural causes operate, and fix no limit, or termination, to the universe. The objects we commonly call great, vanish, when we contemplate the vast body of the earth. The terraqueous globe itself is lost in the solar system; the sun itself dwindles into a star; Saturn's vast orbit, and all the orbits of the comets, crowd into a point, when viewed from numberless places between the earth and the nearest fixed stars. Other suns kindle to illuminate other systems, where our sun's rays are unperceived; but they also are swallowed up in the vast expanse. When we have risen so high, as to leave all definite measures far behind us, we find ourselves no nearer to a term, or limit.

" Our views of nature, however imperfect, serve to represent to us, in a most sensible manner, that mighty power which prevails throughout, acting with a force and efficacy that suffers no diminution from the greatest distances of space or intervals of time; and to prove that all things are ordered by infinite wisdom, and perfect goodness. Scenes which should excite and animate us to correspond with the general harmony of nature."

LECTURE XXXVIII.

EXPLANATION OF THE SEASONS, AND OTHER PHENOMEMA, ON THE COPERNICAN SYSTEM.

I AM now going to consider the earth as a *planet*, having already given you an outline of the solar system, of which the sun is the center, with the seven planetary globes revolving in their respective orbits around him. The earth we inhabit is one of those seven revolving planets, and completes its revolution in 365 days, 5 hours, 49 minutes, which constitutes our year; for it is by this progression or annual motion of the earth, that our year is measured. But besides this, in the space of 24 hours, it makes one complete revolution on its axis, by which motion day and night are alternately occasioned all over the world. To explain the phenomena on these principles, and to remove objections and difficulties, will be the subject of this Lecture; and first of all, it will be necessary to prove to you the globular form of our earth.

OF THE SHAPE, OR FIGURE OF THE EARTH.

I have already observed, that the appearance of the heavenly bodies is not the same to the inhabitants of various parts of the earth; that the sun, the moon, and stars, rise and set in Greenland in a manner very different from what they do in the East Indies, and in both places very different from what they do in England: and as it was natural to attribute the cause of this change in the apparent face of the heavens, to the figure of the earth, for appearances must ever answer to the form and structure of the things; the nature of this figure was, therefore, one of the first objects of inquiry among philosophers and astronomers.

Some sages of antiquity concluded, that the earth must necessarily be of a spherical figure, because that figure was, on many accounts, the most convenient for the earth, as an habitable world: they also argued, that this figure was the most natural, because any body exposed to forces, which tend to one common center, as is the case with the earth, would necessarily assume a round figure. The assent, however, of the modern astronomers to this truth, was not determined by speculative reasoning; but on evidence, derived from facts and actual observation. From these I shall select those arguments, that I think will have the greatest weight.

It is known, from the laws of optics and perspective, that if any body, in all situations, and under all circumstances, projects a circular shadow, that body must be a globe.

It is also known, that eclipses of the moon are caused by the shadow of the earth.

And we find, that whether the shadow be projected towards the east or the west, the north or the south, under every circumstance it is circular; the body, therefore, that casts the shadow, which is the earth, must be of a globular figure.

You will obtain another convincing proof of the globular shape of the earth, by inquiring in what manner a person standing upon the coast of the sea, and waiting for a vessel which he knows is to arrive, sees that vessel. We shall find, that he first of all, and at the greatest distance, sees the top of the mast rising out of the water; and the appearance is, as if the ship was swallowed up in the water. As he continues to observe the object, more and more of the mast appears; at length he begins to see the top of the deck, and by degrees the whole body of the vessel. On the other hand, if the ship be departing from us, we first lose sight of the hull, at a greater distance the main-sails disappear, and at a still greater the top-sail. But if the surface of the sea were a plane, the body of the ship, being the largest part of it would be seen first, and from the greatest distance, and the masts would not be visible till it came nearer.

To render this, if possible, still clearer, let us consider two ships meeting at sea, the top-mast of each are the parts first discovered by both, the hull, &c. being concealed by the convexity of the globe which rises between them. The ships may, in this instance, be resembled to two men, who approach each other on the opposite sides of a hill; their heads will be first seen, and gradually, as they approach, the body will come entirely in view. From hence is derived a rational method of estimating the distance of a ship, which is in use among sea-faring people, namely, of observing, *how low they can bring her down*; that is to say, the man at the mast-head fixes his eyes on the vessel in sight, and slowly descends by the shrouds, till she becomes no longer visible. The less the distance, the lower he may descend before she disappears. If observations of this kind be made with a telescope, the effect is still more remarkable; as the distance increases or diminishes, the ship in sight will appear to become more and more immersed, or to rise gradually out of the water.

This truth is also fully evinced by the following consideration; that ships have sailed round the earth, have gone out to the westward, and have come home from the eastward; or, in other words, the ships have kept the same course, and yet returned from the opposite side into the harbour whence they first sailed. Now we are certain that this could not be the case, if the earth were a plane; for then a person, who should set out for any one point, and go on straight forward, without stopping, would be continually going further from the point from which he set out.

Plate 2, *fig*. 1 and 2, are illustrations of the foregoing principles. *Fig*. 1 shews, that if the earth was a plane, the whole of a ship would be seen at once, however distant from the spectator, and that, whether he be placed at the top or bottom of a hill. From *fig*. 2, it appears, that the rotundity of the earth, represented by the circle A B C, conceals the lower part of the ship d, while the top-mast is still visible; and that it is not till the ship comes to c, that the whole of it is visible.

The following remarks evince the same truth. Observe any star near the northern part of the horizon, and if you travel to the south, it will seem to dip farther and farther downwards, till proceeding on, it will descend entirely out of sight. In the mean time, the stars to the southward of our traveller will seem to rise higher and higher. The contrary appearances would happen, if he went to the northward. This proves, that the earth is not a plane surface, but a curve in the direction south and north. By an observation nearly similar to this, the traveller may prove the curvature of the earth, in an east and west direction.

The globular figure of the earth may be also inferred from the operation of *levelling*, or the art of conveying water from one place to another: for in this process, it is ſound necessary to make an allowance between the true and apparent level; or, in other words, for the ſigure of the earth. For the true level is not a straight line, but a curve which falls below the straight line about eight inches in a mile, four times eight in two miles, nine times eight in three miles, sixteen times eight in four miles, always increasing as the square of the distance.

What the earth loses of its sphericity by mountains and vallies, is very inconsiderable; the highest eminence bearing so little proportion to its bulk, as to be scarcely equivalent to the minutest protuberance on the surface of a lemon.

It is proper, however, to acquaint you, that though we call our earth a globe, and that when speaking in general terms, it may be considered as such; yet in the strictness of truth, it must be observed, that it is not exactly and perfectly a sphere, but is a spheroid, flattened a little towards the poles, and swelling at the equator; the equatorial diameter being about thirty-four miles longer than the diameter from pole to pole.

OF THE DIURNAL MOTION OF THE EARTH.

Though it is this motion which gives us the grateful vicissitude of day and night, adjusted to the times of labour and rest; yet most people find some difficulty in conceiving that the earth moves; the more so, because, in order to allow it, they must give up, in a great measure, the evidence of their exterior senses, of which the impressions are exceeding strong and lively. It will, therefore, be necessary to prove to you, that you can by no means infer, that the earth is at rest, because it appears to be so, and to convince you, by a variety of facts, that reason was given to correct the fallacies of the senses.

To this end we shall here point out some instances, where apparent motion is produced in a body at rest, by the real motion of the spectator. Let us suppose a man in a ship to be carried along by a brisk gale, in a direction parallel to a shore, at no great distance from him; while he keeps his eye on the deck, the mast, the sails, or any thing within the ship; that is to say, while he sees nothing but some part of the vessel on board of which he is, and consequently every part of which moves with him, he will not perceive that the ship moves at all. Let him, after this look to the shore, and he will see the houses, trees, and hills, run from him in a direction contrary to the motion of the vessel; and, supposing him to have received no previous information on this subject, he might naturally conclude, that the apparent motion of these bodies was real.

In a similar situation to this, we may conceive the inhabitants of the earth, who, in early times, knowing nothing of the true structure or laws of the universe, saw the sun, the stars, and the planets, rise and set, and perform an apparent revolution about the earth. They had no idea of the motion of the earth, and therefore all this appearance seemed reality. But as it is highly reasonable to suppose, that as soon as the slightest hint should be given to the man, of the motion of the vessel, he would begin to form a new opinion, and conceive it to be more rational, that so small a thing as the ship should move, rather than all that part of the earth which was open to his view; so, in the same manner, no sooner was an idea formed of the vast extent and greatness of the universe, with respect to this earth, than mankind began to conceive it would be more rational that the earth should move, than the whole fabric of the heavens.

By another familiar instance, it will be easy to shew you, that as the eye does not perceive its own motion, it always judges from appearances. Go into a common windmill, and desire the miller to turn the mill round, while you are sitting within it with your eyes fixed on the upright post in the center thereof; this post, though at rest, will appear to you to turn round with considerable velocity, the real motion of the mill being the cause of the apparent motion of the swivel post.

Sea-faring people are furnished with various instances to illustrate this subject; those who are busy in the hold of a ship at anchor, cannot by any perception determine whether the ship has swung round or not by the turn of the tide. When a ship first gets under way with a light breeze, she may be going at a good rate before those who are between decks can perceive it. Having thus obviated the objections which arise from the testimony of the senses, we may now proceed to consider the arguments which tend more directly to prove the motion of the earth.

All the celestial motions will, on this supposition, be incomparably more simple and moderate.

This opinion is much more agreeable to our notions of final causes, and our knowledge of the economy of nature; for, if the earth be at rest, and the stars, &c. move round it once in twenty-four hours, their velocity must be immense; and it is certainly more agreeable to reason, that one single body, and that one of the smallest, should revolve on its own axis in twenty-four hours, than that the whole universe should be carried round it in the same time, with inconceivable velocity.

The rotation of the earth round its axis is analogous to what is observed in the sun, and most of the planets; it being highly probable, that the earth, which is itself one of the planets, should have the same motion as they have, for producing the same effect; and it would be as absurd in us to contend for the motion of the whole heavens round us in twenty-four hours, rather than allow a diurnal motion to our globe, as it would be for the inhabitants of Jupiter to insist, that our globe, and the whole heavens, must revolve round him in ten hours, that all its parts might successively enjoy the light, rather than grant a diurnal motion to their habitation.

All the phenomena relative to this subject are as easily solved on the supposition of the earth's diurnal motion, as on the contrary hypothesis.

Besides the foregoing considerations, there are several arguments to be deduced from the higher parts of astronomy, which demonstrably prove the diurnal motion of the earth.

OF THE PHENOMENA OCCASIONED BY THE EARTH'S DIURNAL ROTATION.

As the earth is of a spherical figure, that part which at any time comes under the confined view of an observer, will seem to be extended like a plane; and the heavens will appear as a concave spherical superficies divided by the aforesaid plane into two parts, one of which is concealed from us by the opacity of the earth.

Now the earth, by its revolution round its axis, carries the spectator and the aforesaid plane from west to east; therefore all those bodies which could not be seen, because they were below the plane of the horizon, will become visible, or rise above it, when, by the rotation of the earth, the horizon sinks as it were below them. On the other hand, the opposite part of the plane, towards the west, rising above the stars on that side, will hide them from the spectator, and they will appear to set, or go below the horizon.

As the earth, together with the horizon of a spectator, continues moving to the east, and about the same axis, all such bodies as are separated from the earth, and which do not partake of that motion, will seem to move uniformly in the same time, but in an opposite direction, that is from east to west; excepting the celestial poles, which will appear to be at rest. Therefore, when we say, that the whole concave sphere of the heavens appears to turn round upon the axis of the world, whilst the earth is performing one rotation round its own axis, we must be understood to except the two poles of the world, for these two do not partake of this apparent motion.

It is, therefore, on account of the revolution of the earth round its axis, that the spectator imagines the whole starry firmament, and every point of the heaven, excepting the two celestial poles, to revolve about the earth from east to west every twenty-four hours, each point describing a greater or less circle, as it is more or less remote from one of the celestial poles.

Although every place on the surface of the terraqueous globe is illuminated by all the stars which are above the horizon of that place; yet when the sun is above the horizon, his light is so strong, that it quite extinguishes the faint light of the stars, and produces day. When the sun goes below the horizon, or more properly, when our horizon gets above the sun, the stars give their light, and we are in that state which is called night.

Now as the earth is an opake spherical body, at a great distance from the sun, one half of it will always be illuminated thereby, while the other half will remain in darkness.

The circle which distinguishes the illuminated face of the earth from the dark side, and is the boundary between light and darkness, is generally called the *terminator*. A line drawn from the center of the sun to the center of the earth, is perpendicular to the plane of this circle.

When any point in the globe first gets into the enlightened hemisphere, the sun is just risen to that part; when it gets half-way, or to its greatest distance from the terminator, it is then noon; and when it leaves the enlightened hemisphere, it is then sunset; but it still enjoys some light from the sun, which is reflected by the atmosphere, till it gets eighteen degrees beyond the terminator; this glimmering light is called *twilight*.

OF THE CORRESPONDENCE OF THE CELESTIAL AND TERRESTRIAL CIRCLE.

As the earth daily revolves on its axis, every point on its surface is successively presented to all the points in the heavens, describing circles whose planes are perpendicular to its axis, and their centers therein; whence it follows, that those planes are parallel to each other, and may be considered as the elements of a sphere.

Therefore all the stars must seem to turn every day uniformly about the earth's axis, and in parallel circles, as though they were placed in the concavity of a sphere to which the earth is concentric.

The two points at the extremities of the earth's axis whereon it turns, are the only points of its surface that do not change their places; every other point describes a circle greater as it is farther distant from those fixed points or poles.

In the heavens, therefore, there must be two points, P Q, *plate* 2, *fig*. 3, that appear fixed, wherein a star can have no apparent motion; these points are determined in the heavens, by prolonging the axis of the earth; these are the poles of a great circle of the celestial sphere, formed in the heavens by continuing the plane of the terrestrial equator, and all the stars will appear to turn round these two poles.

Thus the axis, p q, of the earth, p e q z, *plate* 2, *fig*. 3, are the poles of a great circle, E T Z, of the celestial sphere, formed in the heavens by continuing the plane of the terrestrial equator e z z, and all the stars will appear to turn round the two poles P, Q, or rather round the axis P Q. Let P represent the north pole, Q the south pole.

If, through the center of the earth C, and any point, m, on its surface, a right line, C m, be supposed prolonged to the heavens, the extremity, M, of that right line will, by the earth's diurnal rotation, describe the celestial parallel L M M L, answering to the terrestrial parallel, l m m l, of the point m. And if C M be supposed to be prolonged on the other side to the heavens in T, then T will describe in the heavens a parallel T T V V, equal to the parallel L M M L, answering to, and having the same declination with the terrestrial parallel t t u u.

Hence it follows, 1. That the plane of the celestial parallel L M M L, and that of the correspondent parallel l m m l, are similar elements of a cone, whose axis is the same as that of the earth, and whose vertex, C, is at the earth's center. *Therefore, the plane of a celestial parallel cannot be the same with its corresponding terrestrial parallel, only the plane,* E Z Z, *of the celestial equator is the same with the plane,* e z z, *of the terrestrial equator.*

2. When, in the earth's diurnal rotation, a star passes through the observer's zenith, the parallel of that star corresponds with the observer's terrestrial parallel; that is to say, the celestial parallel is as far distant from the celestial equator, as the terrestrial parallel is from the terrestrial equator: for then the line of the observer's zenith is a right line drawn

from the earth's center through the observer's eye, terminating at the star, and is the line that describes the star's parallel in the heavens.

If, therefore, the arc M Z, the distance of the star, M, from the celestial equator be measured, it gives also the measure of the arc m z, the observer's distance from the terrestrial equator. *Therefore, the arc of the observer's distance from the terrestrial equator, is equal to the declination of the star that passes through his zenith.* So that if it be a fixed star, and the observer changes his place, the different declinations of the stars that pass through his zenith at the various places he comes to, will shew how much he approaches to, or recedes from the equator.

It follows, lastly, *that any place on the terrestrial sphere may be represented by its corresponding zenith point in the heavens.* For the celestial parallel passing through that point, represents the terrestrial parallel of the place, and the declination of the celestial parallel measuring the distance of that place from the equator; also the great circle of the celestial sphere described from that zenith as a pole, denotes the plane of the horizon of that place, and the particular phenomena of a place on the earth may be explained, by denoting that place no otherwise than by its zenith in the heavens.*

OF THE ANNUAL MOTION OF THE EARTH.

It is owing to the industry of modern astronomers, that the annual motion of the earth has been fully evinced; for though this motion had been known to, and adopted by many among the ancient philosophers, yet they were not able to give their opinions that degree of probability, which is attainable from modern discoveries, much less the evidence arising from those demonstrative proofs, of which we are now in possession. I shall, therefore, enumerate some of the reasons which induce astronomers to believe, *that the earth moves round the sun*, and then explain further the nature of this motion, which is calculated to afford us the useful and delightful variety of the seasons, the mutual allay of immoderate heat and cold, and the successive growth and recruit of vegetation.

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* The whole of what is said, under this head, may be clearly illustrated by the armillary sphere.

On the supposition of the earth's motion, the celestial motions become incomparably more simple, and free from those looped contortions which must be supposed in the other case, and which are not only extremely improbable, but incompatible with what we know of motion.

This opinion is also more reasonable, on account of the extreme minuteness of the earth, when compared with the immense bulk of the sun, Jupiter, and Saturn; and there are no known laws of motion, according to which so great a body as the sun can revolve about so small a one as the earth.

The sun is the fountain of light and heat, which it darts through the whole system; it ought, therefore, to be in the center, that its influence may be regularly diffused through the whole heavens, and communicated in just gradations to the whole system.

When we consider the sun as the center of the system, we find all the bodies moving round it, agreeable to the universal laws of gravity; but upon any other consideration we are left in the dark.

The motion of the earth round the sun accords with that general harmony, and universal law, which all the other moving bodies in the system observe, namely, *that the squares of the periodic times are as the cubes of the distances*; but if the sun moves round the earth, that law is destroyed, and the general order of symmetry in nature interrupted.

The annual motion of the earth is incontestibly proved by observation, a motion having been discovered in all the fixed stars, which arises from a combination of the motion of light with the motion of the earth in its orbit.

It will be clearly shewn in its place, that Venus and Mercury move round the sun in orbits that are between it and the earth; that the orbit of the earth is situated between that of Venus and Mars; and that the orbits of Mars, Jupiter, &c. are exterior to, and include the other three.

OF THE APPARENT MOTION OF THE SUN, ARISING FROM THE EARTH'S ANNUAL MOTION ROUND IT.

As when a person sails along the sea coast, the shore, the villages, and other remarkable places on land, appear to change their situation, and to pass by him; so it is in the heavens. To a spectator upon the earth, as it moves along its orbit, or sails as it were through celestial space, the sun, the planets, and the fixed stars, appear to change their places.

Apparent change of place is of two sorts; the one is, that of bodies at rest, the change of whose place depends solely on that of the spectator; the other is, that of bodies in motion, whose apparent change of place depends as well on their own motion, as on that of the spectator.

I shall first consider only that apparent change which takes place in those which are at rest, and which is owing wholly to the motion of the earth; and shew that the sun, when seen from the earth, will appear to move in the same manner, whether it revolves round the earth, or whether the earth revolves round the sun.

Let us suppose the earth at rest, without any motion of its own, and let the sun be supposed to revolve round it in the orbit A B C D, *plate* 4, *fig*. 1, and let E F G H be a circle in the concave sphere of the starry heavens; as the sun moves in the order of the letters, A B C D, in its orbit, it will appear to a spectator on the earth to have described the circle E F G H. When the sun is at A, it will appear as if it was among the fixed stars that are at E; when it is at B, it will appear among the fixed stars at F; when at G, among those at H; and when it is at D, it will appear among the fixed stars at G. Indeed, the fixed stars and the sun are not seen at the same time; but I have shewn, that we may tell in what part of the heavens the sun is, or what fixed stars it is near, by knowing those which are opposite to it, or come to the south at midnight. Therefore, if we find that any set of stars, as those at G for instance, come to the south at midnight, we may be sure that they are opposite to the sun; and, consequently, if we could see the stars in that part of the heaven where the sun is, we should find them to be those at F.

Secondly, let us suppose that S is the sun, that it has no motion of its own, that it rests within the orbit A B C D, in which we shall now suppose the earth to move, in the order of the letters A B C D. Upon this supposition, when the earth is at A, the sun will appear in that part of the heavens where the stars, H, are; when the earth is at B, the sun will appear in that part of the heavens where the stars, G, are; when the earth is at C, the sun will appear in that part of the heavens where the stars, E, are; and as the earth revolves round the sun, in the orbit A B C D, the sun will appear to a spectator on the earth to describe the circle E F G H.

Thus, whether the earth be at rest, and the sun revolves in the orbit A B C D; or the sun be at rest, and the earth revolves in the same orbit, a spectator on the earth will see the sun describe the same circle, E F G H, in the concave sphere of the heavens.*

Hence, if the plane of the earth's orbit be imagined to be extended to the heavens, it would cut the starry firmament in that very circle in which a spectator in the sun would see the earth revolve every year: while an inhabitant of the earth would observe the sun to go through the same circle, and in the same space of time that the solar spectator would see the earth describe it.

The inhabitants of all the other planets will observe just such motions in the sun as we do, and for the very same reasons; and the sun will be seen from every planet to describe the same circle, and in the same space of time, that a spectator in the sun would observe the planet to do. For example, an inhabitant of Jupiter would think that the sun revolved round him, describing a circle in the heavens in the space of twelve years: this circle would not be the same with our ecliptic, nor would the sun appear to pass through the same stars which he does to us. On the same account, the sun, seen from Saturn, will appear to move in another circle, distinct from either of the former; and will not seem to finish his period in less time than thirty years. Now, as it is impossible that the sun can have all these motions really in itself, we may safely affirm, that none of them are real, but that they are all apparent, and arise from the motions of the respective planets.

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* This is pleasingly illustrated by the armillary sphere, where the sphere may be moved independent of the earth, and the earth of the sphere.

One phenomenon arising from the annual motion of the earth, which has already been slightly touched upon, may now be more fully explained; for as from this motion, the sun appears to move from west to east in the heavens, if a star rises or sets along with the sun at any time, it will, in the course of a few days, rise or set before it, because the sun's apparent place in the heavens will be removed to the eastward of that star. Hence those stars which, at one time of the year, set with the sun, and therefore do not appear at all, shall, at another time of the year, rise when the sun sets, and shine all the night. And as any one star shifts its place with respect to the sun, and in consequence of that with respect to the hour of the night, so do all the rest. Hence it is, that all those stars, which at one time of the year appear on any one side of the pole star in the evening, shall, in half a year, appear on the contrary side thereof.

From what has been said it follows in general, 1. *That, in whatever regards the sun's place, only with respect to the point in the heavens in which it appears, it may be supposed to move in an infinitely great circle, called the ecliptic, whose center is the observer's eye.*

2. *That the earth's true place in his orbit being known, from observation or calculation; six signs added to or subtracted from it, gives the sun's true place in the ecliptic.* Therefore the theory of the sun's motion seen from the earth, is the same with that of the earth's motion seen from the sun.

3. *To an inhabitant of the earth, the plane of the ecliptic is that, whereto the annual motions of the planets in their orbits must be naturally compared.* In the same manner, as the plane of the equator is that whereto the position of the parallels, which the stars appear to describe in consequence of the earth's diurnal revolution, must also be compared.

In order to combine the sun's annual motion with its diurnal, you are to observe, that if the plane of the ecliptic coincided with that of the equator, the sun would, by its diurnal revolution, seem to describe every day the same circle, viz. the equator; and therefore could have no declination. For, in describing the ecliptic by its annual revolution, the sun would then successively answer to all the stars in the equator, consequently, its diurnal revolution would be made in the same circle as that of the stars; but I have already observed to you, that the sun appears to describe daily different parallels; it is evident, therefore, that the plane of the ecliptic does not coincide with that of the equator, but is inclined thereto.

If so, the sun must, in consequence of its annual motion, describe a great circle N B T L N, *plate* 2, *fig*. 4, representing the ecliptic, and bisecting the equator E B Z L E. The sun must therefore appear sometimes towards one pole, and sometimes towards the other pole.

1. Let us suppose that it is in B, one of the intersections of the equator and the ecliptic, its diurnal revolution must describe the equator, and have no declination; as the sun gradually advances in the ecliptic from B towards A, it appears gradually to recede from the equator with an increasing northern declination, and to describe smaller and smaller parallels, till it arrives at A, where it appears to describe the parallel A I V A.

2. The sun being arrived at L, three signs or 90 degrees from B, and three months after his departure therefrom, it is then in that point of the ecliptic the most distant from the equator at its greatest northern declination, and describes the smallest parallel O T.

3. In the three following months the sun going from T to L, draws nearer the equator, its northern

declination diminishes, its parallels augment; so that when arrived in L, the other intersection of the equator and the ecliptic, it then has no declination, and on that day again describes the celestial equator.

4. The sun after that, passing from L to N, enters the south part of the heavens, its southern declination then increases, and its parallels diminish, till being come to N, three signs from the point L, its southern declination is then the greatest, and it describes its least parallel N D.

5. The sun, continuing its course from N to B, again draws nearer the equator, and its southern declination diminishes; so that when returned to B, a year after its departure from that point, it is again in the equator and without declination, and then begins a new course attended with the same phenomena.

It is evident, therefore, *that the sun moving continually in the ecliptic, the parallels it every day describes cannot be circles, but a kind of spirals,* such as the curves made by a thread wound about a sphere. For after a diurnal revolution, the sun does not come to the same point from whence it departed, but according as it approached to, or receded from the equator, is either a little below or above that point.

The angle formed by the plane of the equator and ecliptic, is called the *obliquity of the ecliptic.*

The obliquity of the ecliptic is equal to the sun's greatest declination, namely, when in the tropic, and is about 23½ degrees; consequently, the axis of the earth must be inclined to the ecliptic in an angle 66½ degrees. The consideration of this obliquity brings us to an explanation.

OF THE SEASONS OF THE YEAR.

It is our business under the present head to account for the phenomena of the seasons, those grateful vicissitudes on which so much both of the business and happiness of man depends.

Before I explain the causes of those changes that are termed the *seasons of the year,* it will be necessary to premise a few considerations: First, that on account of the immense distance of the sun from the earth, the rays which proceed from it may be considered as parallel to each other. Secondly, that only one-half of the globe can be illuminated by parallel rays, and therefore only one-half the earth will be enlightened by the sun at one time. Thirdly, that we may call the line, which divides light from darkness, the terminator.

In the diagram, *plate* 5, *fig.* 1, S represents the sun, from which we suppose parallel rays to flow in all directions; A, B, C, represent three different positions of the globe of the earth, the bright part being that which is illuminated by the rays proceeding from the sun; the dark part, the portion of the globe which is in obscurity at these different situations; N the north, S the south pole of the globe, T T the terminator, or boundary of light and darkness.

At C, the poles coincide with the terminator.

At A, the north pole is altogether in the *illuminated* hemisphere, and the south pole in the *dark* hemisphere.

At B, the southern pole is in the *enlightened* part, and the north pole in the *dark* hemisphere.

It is evident, that it is day in any given place on the globe, so long as that place continues in the enlightened hemisphere; but when, by the diurnal rotation of the earth on its axis, it is carried into the dark hemisphere, it becomes night to that place.

The length of the day and night depend on the position of the terminator, with respect to the axis of the earth.

If the poles of the earth be situated in the terminator, as at C, every parallel will be divided into two equal parts; and as the uniform motion of the earth causes any given place to describe equal parts of its parallel in equal times, the day and night would be equal on every parallel of latitude, that is, all over the globe, except at the poles, where the sun would neither rise nor set, but continue in the horizon.

But if, as at A and B, the axis be not placed in the plane of the terminator, the terminator will divide the equator into two equal parts, but all the circles parallel to it into unequal parts; those circles that are situated towards the enlightened pole, will have a greater part of their circumference in the enlightened than in the dark hemisphere; while similar parallels towards the other pole will have the greater part of their circumference in the dark hemisphere. Whence it follows, that the first-mentioned parallels will enjoy longer days than nights; and the contrary will happen to the latter, where the days will be the shortest, and the nights the longest; while at the equator, the days and nights continue equal. All this is evident from the bare inspection of the figures; it is also observable, that the disproportion is greatest in the greatest latitude; and that those places, whose distance from the pole is less than that of the pole from the terminator, must enjoy either a constant day, or a constant night, because they are never carried into the opposite hemisphere by the diurnal rotation of the earth. In this position of the axis, the inhabitants on one side of the equator may be said to enjoy summer, and those on the other side, winter, with respect to each other.

From what has been said, it is plain, that the vicissitudes in the days and nights are occasioned by the position of the terminator, or boundary of light and darkness, with the axis of the earth; or, in other words, by the different aspect of the earth with respect to the sun.

We have now only to shew what causes the changes of position in the terminator, which are, 1. The inclination of the earth's axis to the plane of the ecliptic, or orbit in which it moves. 2. That through the whole of its annual course, the axis of the earth preserves its position, or continues parallel to itself; that is, if a line be conceived as drawn parallel to the axis while the earth is in any one point of its orbit, the axis will in every other position of the earth be parallel to the said line.

If the axis of the earth were perpendicular to the plane of its orbit, the equator and the orbit, or ecliptic, would coincide; and as the sun is always in the plane of the ecliptic, it would in this case be always over the equator, and the two poles would be in the terminator, and there would be no diversity in the days and nights, and but one season in the year: but as this is not the case, we may fairly infer, that the axis of the earth is not perpendicular to the plane of its orbit.

But, if the earth's axis be inclined to the plane of the ecliptic, when the earth is in the situation represented at A, *plate* 5, *fig*. 1, the pole N will be towards the sun, and the pole S will be turned from it; but just the contrary will happen, when the earth, by going half round the sun, has arrived at the opposite point in its orbit. Hence the sun will not be always in the equator, but at one time of the year it will appear nearer to one of the poles, and at the opposite season, it will appear nearer to the other. To this circumstance the change of seasons is owing; for when the sun leaves the equator and approaches to one of the poles, it will be summer on that side of the equator, and when the sun departs from thence and approaches to the other pole, it will be winter. Thus, from the inclination of the axis, each part of the earth enjoys the benefit of summer in its turn; for it is evident, from what has been said already, that when it is winter towards one of the poles, on one side the equator, it is summer towards the other pole, or on the other side of the equator.

A better notion of the effect of the inclination of the earth's axis will be obtained by observing *plate* 5, *fig.*2, in which the ellipsis represents the earth's orbit, seen at a distance; the eye being supposed to be elevated a little above the plane of it. The earth is here represented in the first point of each of the twelve signs, as marked in the figure, with the twelve months annexed; e is the north pole, and e d the axis of the ecliptic, always perpendicular to the plane of the orbit; P the north pole of the world; P m its axis, about which the earth's daily motion is made from west to east. P C E shews the angle of its inclination, which preserves its parallelism through every part of its orbit.

When the earth is in the first point of Aries, the sun then appears in the opposite point of the ecliptic at Libra, about the twenty-second of September, N.S. and when the earth is in Libra, the sun will then appear in Aries about the nineteenth of March; at which times of the year the edge of the enlightened hemisphere is parallel to the solstitial colure, and passes through the two poles of the world, dividing every parallel to the equator into two equal parts; whence the diurnal parallel of every inhabitant on the surface of the earth will, at either of these seasons, be half in the illuminated, and half in the obscure part of the earth; consequently, the day and night will be equal in all places.

Conceive the earth to have moved from ♎ Libra to ♑ Capricorn, its line of direction keeping its parallelism will now coincide with the solstitial colure, and the edge of the disk will be perpendicular thereto, and pass through e, the pole of the ecliptic. In this situation of the earth, all places within the northern polar circle are illuminated throughout the whole diurnal revolution, at which time their inhabitants see the sun longer than twenty-four hours; but those which lie under the polar circle touch the edge of the disk, and therefore their inhabitants only see the sun skim quite round their horizon as at its first appearance. Every other parallel intersects the edge of the disk, and as the illuminated part of each is much greater than the obscure part, the days are, consequently, at this season of the summer solstice, which happens about the twenty-first of June, longer than the nights. While the earth is moving from Libra through Capricorn to Aries, the north pole, P, being in the illuminated hemisphere, will have six months continual day; but while the earth passes from Aries through Cancer to Libra, the north pole will be in the obscure parts, and have continual nights, the south pole of the globe at the same time enjoying continual day. When the earth is at Cancer, the sun appears at Capricorn. At this season the nights will as much exceed the days, as the days exceeded the nights when the earth was in the opposite point of her orbit; for the nocturnal arcs, or obscure part of their paths, are here equal to the illuminated parts when the earth was at Capricorn; and the illuminated part is here no more than the obscure part was in that place.

By considering the three globes, A, B ,C, *plate* 5, *fig.* 1, you may gain a clear idea of the daily apparent change in the sun's declination; there is a line drawn from the center of the sun to the center of each globe; it is broader than the other lines. This line may be called the *central solar ray.* About the twenty-first of December, when the earth is in Cancer, this ray will terminate, or fall upon the southern tropic, as at D; or the tropic of Capricorn, as at B; and, consequently, by the earth's rotation round her axis, the inhabitants of every part of this circle will successively have the sun in their zenith; or, in other words, he will be vertical to them that day at noon, as the sun appears that day to be carried round in the tropic of Capricorn.

About the twentieth of March, the earth is at Libra, and the sun will then appear in Aries; the central solar ray terminates upon the surface of the earth, in the equator, as at C; and therefore the sun appears to be carried round in the celestial equator, and is successively vertical to those who live under that circle.

About the twenty-first of June, when the earth is in Capricorn, the central solar ray terminates on the surface of the earth, in the northern tropic, as at A; and for that day the sun appears to be carried round in the tropic of Cancer, and is vertical to those who live under that circle. About the twenty-second of September, the earth is in Aries, and the sun in Libra, and the central solar ray again terminates at the equator; consequently, the sun again appears in the celestial equator, and is vertical to those who live under it.

We have seen, that as the sun moves in the ecliptic, from the vernal equinox to the tropic of Cancer, it gets to the north of the equator, or its declination towards our pole increases. Therefore, from the vernal equinox, when the days and nights are equal, till the sun comes to the tropic of Cancer, our days lengthen, and our nights shorten; but when the sun comes to the tropic of Cancer, it is then in its utmost northern limit, and returns in the ecliptic to the equator again. During this return of the sun, its declination towards our pole decreases, and consequently the days decrease, and the nights increase, till the sun is arrived in the equator again, and is in the autumnal equinoctial point, when the days and nights will again be equal. As the sun moves from thence towards the tropic of Capricorn, it gets to the south of the equator; or its declination towards the south pole increases. Therefore, at that time of the year, our days shorten, and our nights lengthen, till the sun arrives at the tropic of Capricorn; but when the sun is arrived there, it is then at its utmost southern limit, and returns in the ecliptic to the equator again. During this return, its distance from our pole lessens, and consequently the days will lengthen, as the nights will shorten, till they become equal, when the sun is come round to the vernal equinoctial point.

Our summer is nearly eight days longer than the winter.

By summer is meant here the time that passes between the vernal and autumnal equinoxes; by winter, the time between the autumnal and vernal equinoxes. The ecliptic is divided into six northern, and six southern signs, and intersects the equator at the first of Aries, and the first of Libra. In our summer, the sun's apparent motion is through the six northern, and our winter through the six southern signs; yet the sun is 186 days, 11 hours, 51 minutes, in passing through the six first; and only 178 days, 17 hours, 58 minutes, in passing through the six last. Their difference, 7 days, 17 hours, 53 minutes, is the length of time by which our summer exceeds the winter.

In *plate* 6, *fig.* 1, A B C D represents the earth's orbit; S the sun in one of its foci; when the earth is at B, the sun appears at H, in the first point of Aries; and whilst the earth moves from B, through C to D, the sun appears to run through the six northern signs, from ♈ through ♋ to ♎ at F. When the earth is at D, the sun appears at F, in the first point of Libra; and as the earth moves from D, through A to B, the sun appears to move through the six southern signs, from ♎ through ♑ to Aries at H.

Hence the line F H, drawn from the first point of Aries, through the sun at S, to the first point of ♎, divides the ecliptic into two equal parts; but the same line divides the earth's elliptical orbit into two unequal parts. The greater part, B C D, is that which the earth describes in the summer, while the sun appears in the northern signs. The lesser part is D A B, which the earth describes in winter, while the sun appears in the southern signs. C, the earth's aphelion, where it moves slowest, is in the greater part; A, its perihelion, is in the lesser part, where the sun moves fastest.

There are, therefore, two reasons why our summer is longer than our winter; first, because the sun continues in the northern signs, while the earth is describing the greater part of its orbit; and secondly, because the sun's apparent motion is slower while it appears in the northern signs, than whilst it appears in the southern ones.

The sun's apparent diameter is greater in our winter than in summer, because the earth is nearer to the sun when at A, in the winter, than it is when at C, in the summer. The sun's apparent diameter, in winter, is 32 minutes, 47 seconds; in summer, 31 minutes, 40 seconds.

But if the earth is farther from the sun in summer than in winter, it may be asked, why our winters are so much colder than our summers. To this it may be answered, that our summer is hotter than the winter, first, on account of the greater height to which the sun rises above our horizon in the summer; secondly, the greater length of the days. The sun is much higher at noon in summer than in winter, and consequently, as its rays in summer are less oblique than in winter, more of them will fall upon the surface of the earth. In the summer, the days are very long, and the nights very short; therefore the earth and air are heated by the sun in the day-time, more than they are cooled in night; and, upon this account, the heat will keep increasing in the summer, and for the same reason will decrease in winter, when the nights lengthen.

I should exceed the limits of a Lecture, if I were to inquire into the several concurring causes of the temperatures that obtain in various climates; it may be sufficient, therefore, to observe what a remarkable provision is made in the world, and the several parts of it, to keep up a perpetual change in the degrees of heat and cold. These two are antagonists, or, as Lord *Bacon* calls them, "the very hands of nature with which she chiefly worketh," the one expanding, the other contracting bodies, so as to maintain an oscillatory motion in all their parts; and so serviceable are these changes in the natural world, that they are promoted every year, every hour, every moment. From the oblique position of the ecliptic, the earth continually presents a different face to the sun, and never receives his rays two days together in the same direction. In the day and night, the differences are so obvious, that they need not to be mentioned, though they are most remarkable in those climates, where the sun at his setting makes the greatest angle with the horizon. Every hour of the day, the heat varies with the sun's altitude, is altered by the interposition of clouds, and the action of winds; and there is little room to doubt, but what the various changes that thus take place, concur in producing many of the smaller and greater phenomena of nature.

Be this however as it may, it is certain, that the various irregularities and intemperatures of the elements, which seem to destroy nature in one season, serve to revive it another: the immoderate heats of summer, and the excessive cold of winter, prepare the beauties of the spring, and the rich fruits of autumn. These vicissitudes, which seem to superficial minds the effects of a fortuitous concourse of irregular causes, are regulated according to weight and measure by that Sovereign Wisdom, who weighs the earth as a grain of sand, the sea as a drop of water.

Our observations on the seasons cannot be better concluded than in the words of the excellent *Hooker*. A long and uninterrupted enjoyment of blessings is apt to extinguish in us that gratitude towards the Author of them, which it ought to cherish and invigorate; the course of nature often glides on unobserved when there are no variations therein; and the sun himself shineth unnoticed, because he shineth every day. Since the time that God did first proclaim the edicts of his law, says *Hooker*, heaven and earth have hearkened unto his voice, and their labour has been to do his will. But if nature should intermit her course, and leave altogether, though it were but for a while, the observation of her laws; if those principles and mother elements, whereof all things in this world are made, should lose the qualities they now posses; if the frame of that heavenly arc erected over our heads should loosen and dissolve itself; if the celestial globes should forget their wonted motions, and by irregular volubility turn themselves any way as it might happen; if the prince of the lights of heaven, which now as a giant doth run his unwearied course, should as it were, through a languishing faintness, begin to stand and to rest himself; if the moon should wander from her beaten way, the times and seasons of the year blend themselves together by disorder and confused mixture, the winds breathe out their last gasp, the clouds yield no rain, the earth be defeated of heavenly influence, and her fruits pine away as children at the withered breasts of their mother, no longer able to yield them relief; what would become of man himself, whom all those things do now serve? And how would he look back on those benefits, for which, when they were daily poured upon him in boundless profusion, he forgot to be thankful?

LECTURE XXXIX.

AN EXPLANATION OF THE PHENOMENA OF THE PLANETS, ACCORDING TO THE COPERNICAN SYSTEM.

I SHALL here define again some words which I have already explained, and recal your attention to some circumstances which I have mentioned in a former Lecture. These repetitions will not, I hope, be an object of complaint, as they will render this Lecture more perfect, and answer the beneficial purpose of grounding you more firmly in the science we are now treating of.

The line that a planet describes round the sun is called its *orbit*; the motion of all the planets in their orbits is from west by the south to the east; this is called their *annual* motion.

The orbits of the planets are not all in the same plane, but in planes inclined to each other, or intersecting each other at different angles. The orbit of the earth is taken as a standard, from whence their respective inclinations are computed.

The planes of the several orbits of the planets produced to the fixed stars, mark the several circles which each planet would appear to describe in the sphere of the heaven to a spectator placed in the sun; these circles may be called the *heliocentric orbits* of the planets.

The heliocentric orbit of the earth is the *ecliptic:* to a spectator in the sun, the earth will appear to go round the sun in the ecliptic eastward in twelve months.

We may suppose as many great circles as we please to be described upon the sphere of the heavens, intersecting one another at the poles of the ecliptic, and cutting it at right angles; these are termed *secondaries of the ecliptic*, and *circles of latitude*. The *latitude* of a planet or star is its distance from the ecliptic, measured in degrees, &c. upon a circle of latitude passing through the star or planet.

The latitude a planet would appear to have, when viewed from the sun, is its *heliocentric latitude*; that which it appears to have to an inhabitant of the earth, is called its *geocentric latitude*.

By the place of a planet is meant the place of its center; its geocentric place is that where it appears to an inhabitant of the earth.

The two points where the ecliptic is cut by the heliocentric orbit of a planet, are the nodes of the planet. The *ascending node*, ☊, is the point where the ecliptic is cut by the planet, before it deviates northward therefrom; the *descending node*, ☋, is the point where the planet cuts the ecliptic before it deviates southward.

When any planet has passed its ascending node, it deviates more and more northward till it has got ninety degrees from the node, then it is at its utmost heliocentric northern latitude, or northern limit; from thence it continually approaches the ecliptic, till it comes to ☋, after passing which it deviates more and more southward, till it is ninety degrees from this node, when it is at its southern limit, or utmost southern heliocentric latitude, which from thence continually decreases till the planet returns again to the ascending node. A planet seen from the earth, only appears in the ecliptic when it is in one of its nodes.

The equator cuts the ecliptic in two opposite points; when the sun appears in one of these points, it is our *vernal*; when in the other, it is our *autumnal equinox*. The point of the vernal equinox is counted the first point of the ecliptic, because spring begins the astronomical year; this point is marked ♈ Aries.

The *longitude* of a celestial object is the number of degrees, &c. contained upon the ecliptic, reckoning from ♈ eastward, to the point where a circle of latitude drawn through the object cuts the ecliptic. The longitude and latitude of an object being given, its place in the sphere of the heavens is known; and its place is usually expressed, by saying it is in such a degree and minute of such a sign, and in such latitude.

A planet is said to be in *conjunction* with the sun, when its geocentric place is very near the geocentric place of the sun; that is, when the sun is between our earth and the planet, or when the planet is between the earth and the sun.

A planet is said to be in *opposition*, when its geocentric place is opposite to the geocentric place of the sun; that is, when the earth is between the sun and the planet.

An exact or central conjunction or opposition can happen only when a planet is in one of its nodes; it is, however, usual to term it a conjunction or opposition, when the same secondary of the ecliptic passes through the sun or any planet, though the planet has latitude.

When the geocentric place of a planet is a quarter of a circle distant from the geocentric place of the sun, the planet is said to be in *quadrature*.

A planet is said to be *direct*, when its geocentric motion is eastward; *retrograde*, when westward; *stationary*, when its geocentric place continues the same for some time.

The distance an inferior planet seen from the earth appears to be from the sun, is called its *elongation*.

OF THE CONJUNCTIONS AND ELONGATIONS OF THE INFERIOR PLANETS, MERCURY AND VENUS.

There are two different situations, in which an inferior planet will appear in conjunction with the sun; one, when the planet is between the sun and the earth; the other, when the sun is between the earth and the planet.

Let A, *plate* 6, *fig*. 2, be the earth in its orbit, E the place of Venus in E H G her orbit, S the sun, F V P Q R T D an arc in the starry heaven.

In the situation of things represented in this diagram, the sun and Venus will appear in the same point of the heavens, and so be in conjunction. If Venus be at G, there will also be a conjunction. When the planet is at E, nearer to the earth than the sun, it is called its *inferior conjunction*; but when the planet is at G, farther from the earth than the sun, it is termed the *superior conjunction* of the planet.

When the planet is either at E or G, it has no elongation; but as the planet moves from E to y, its elongation increases; for, when it is at y, it appears in the line A y P, while the sun appears in the line A S Q; so that P A Q will be the angular measure of its elongation or distance from the sun. When the planet arrives at x, it appears in the line A x V, which is a tangent to its orbit, and then V A Q is the angular measure of its elongation; which is the greatest that can be on that side the sun, for, after this, the elongation decreases. When the planet is at K, its elongation is P A Q; when at G, it is nothing, because it is then in its superior conjunction; as the planet moves on from G, its elongation again increases; for, when it comes to C, it appears in the line A C R, and its elongation is R A Q. When the planet comes to H, a line drawn from the earth through the planet is a tangent to the orbit, and the elongation is T A Q, the greatest it can have when it is on the other side of the sun; for, after this, the elongation again decreases.

Hence it is clear, that the inferior planets can never appear far from the sun, but must always accompany it in its apparent motion through the ecliptic. When we see either Venus or Mercury, it is either in an evening in the west, soon after the sun has set; or in a morning, a little before the sun rises. Venus is indeed bright enough sometimes to be seen in the day-time, but then she is never far from the sun. The greatest elongation of Venus is about 47, and of Mercury about 28 degrees.

If the earth be at A, *plate* 6, *fig.* 2, when Venus appears in any part of the arc E x G, she is westward from the sun, and therefore rises before him in the morning, and is called the *morning star.* When she appears any where in the arc G H E, she is eastward from the sun, and therefore sets after him; is seen in the evening, and is called the *evening star.*

FALSITY OF THE PTOLEMAIC SYSTEM.

From the apparent motion of the inferior planets, we derive an argument to shew the falsity of the Ptolemaic system. If the earth was within the orbit of Venus, as this system supposes, she might be sometimes on one side the earth whilst the sun was on the opposite side; in other words, Venus might be sometimes in opposition: but Venus is never seen in opposition, therefore the earth is not within the orbit of Venus, and consequently the Ptolemaic system is not true. The same reasoning applies to Mercury.

OF THE RETROGRADE, STATIONARY, AND DIRECT MOTIONS OF MERCURY AND VENUS.

It is easy, on the Copernican system, to explain why the inferior planets appear to move sometimes in one direction, sometimes in a contrary one, and at other times to be stationary; for it is the natural result of the respective situations and motions of the earth and these planets. But on the Ptolemaic system, it is inexplicable without calling in the aid of a very complicated hypothesis.

When the inferior planets are passing from their greatest elongation, on one side of the sun, through their superior conjunction, to their greatest elongation on the other side, their motion, as viewed from the earth, is direct. In order to explain this proposition, we shall first suppose the earth to be at rest at A, *plate* 6, *fig*. 2, and correct this supposition afterwards, by shewing that the apparent motion of Venus or Mercury, E, seen from the earth, is the same in this respect, whether the earth moves in its orbit, or rests at A.

The proposition to be explained is this; that as Venus, for instance, moves from x, its greatest elongation on one side of the sun, through G its superior conjunction, to H its greatest elongation on the other side, it will appear to a spectator upon the earth to move from west to east according to the order of the signs; that is, its geocentric motion will be direct.

The planets move round the sun from west to east, and consequently if there were a spectator at the sun, they would appear to him to move through the zodiac, according to the order of the signs; or, in other words, the heliocentric motion of Venus is direct. Now, if the sun and the earth A, are both on the same side of the planet, a spectator at the earth is in the same situation with respect to the planet and its motion, as if he had been at the sun; for, whilst the planet is moving from x, through G to H, a spectator either at A or B is on the concave side of the planet's orbit; and consequently the planet will appear to move in the same manner from either; but the apparent motion of the planet, when seen from the sun, is direct, and consequently its motion, when seen from the earth, will also be direct.

When Venus is at x, it appears to a spectator on the earth, at A, to be in the line A x V, or is seen among the stars at V; when Venus has moved to K, it is seen among the fixed stars at P; when it has moved to G, it is in its superior conjunction; when it has moved to C, it appears among the fixed stars at R; and when it is come to K, it appears among the fixed stars at T. Thus, whilst Venus has moved in its orbit from x, its greatest elongation on one side of the sun, through G, its superior conjunction, to H, its greatest elongation on the other side, it appears to have described the arc V P Q R T, in the concave sphere of the heavens; but the letters, x K G C H lie from west to east, because they lie in the same direction that the planet moves round the sun; and the letters V P Q R T lie in the same direction with x K G C H. Therefore, as the planet seems to a spectator on the earth to describe the arc V P Q R T, its apparent motion seen from the earth is direct, or from west to east.

As the inferior planets move from their greatest elongation on one side of the sun, through their inferior conjunction, to their greatest elongation on the other side, their geocentric motion is retrograde.

Whilst Venus, for instance, is moving from its greatest elongation H, through its inferior conjunction E, to its other greatest elongation x, it appears to a spectator upon the earth at A, to move backwards or from east to west, contrary to the order of the signs.

A spectator at the sun is on the concave side of the planet's orbit. But whilst Venus is moving from its greatest elongation H, on one side, through E its inferior conjunction, to *x*, its greatest elongation on the other side, a spectator upon the earth is on the convex side of its orbit.

Therefore, if a spectator at the sun, S, would see the planet move one way, a spectator at the earth, A, will see it move the contrary way; or the geocentric motion will be contrary to its heliocentric motion, and therefore retrograde; for, as seen from the sun, its motion is always direct.

That two spectators, one at the earth, the other at the sun, as they are on contrary sides of the arc H E *x*, will see the planet apparently move contrary ways, may be rendered more plain by the following familiar consideration. If two men stand with their faces towards each other, and a ball is rolled along upon the ground, this ball will move from the right hand of one of the men towards his left, and from the left hand of the other towards his right. In like manner, if one man is at the earth A, and the other at the sun S, then, whilst the planet is describing the arc H E *x*, which is between them, it will appear to move from the right hand of the man at S towards his left, and from the left hand of the man at A towards his right.

Whilst the motion of Venus is direct, or while it is describing the arc *x* G H, it appears to move from V to T, among the fixed stars. But, after it has been carried in its orbit from H to *z*, it appears in the line A z R, and is seen among the fixed stars at R. When it comes to E, it appears at Q; and when at y, its apparent place in the heavens is at P. Thus, as the planet passes from its greatest elongation H, on one side of the sun, through its inferior conjunction E, to its greatest elongation x, on the other side, it apparently goes back from T to V.

Venus is stationary, or has no apparent motion for some time, when it is at its greatest elongation; that is, when it is at H or x, and its apparent place is either at T or V.

When either of the inferior planets, Venus for instance, is at its greatest elongation H or x, a line drawn from the earth through the planet, as A H T or A x V, is a tangent to the orbit. Now, though a right line touches a circle but in one point, yet some part of the circle greater than a point is so near to the tangent, as not to be distinguished from it. Thus the arc at H, so nearly coincides with the tangent A H T, that a spectator's eye placed at A, could not distinguish the tangent from this part of the curve. Consequently, while the planet is describing this arc, no other change will be made in its geocentric place, than if it was to move in the tangent.

But the geocentric place of the planet would not be altered, if the planet was to move in the tangent. For, if it was to move from T towards A, or from A to V, the apparent place of it in the heavens would in one case be at T, in the other case at V. Therefore, while the planet is at its greatest elongation, and is describing a small arc in its orbit, that nearly coincides with the tangent, its geocentric place does not alter, but it appears to continue for some time in the same part of the heavens, or is stationary.

We have hitherto supposed the earth to be at rest, and upon that supposition have explained the progress and regress, the conjunctions and stations of the inferior planets. If this supposition was true, V T, or the arc which the planet at any time describes in its progress, and T V, the arc which it describes in its regress, would always be in the same part of the heavens. The planet, when in conjunction, would always appear at Q, among the same fixed stars; and at its elongation, or when it is stationary, it would always appear among the same fixed stars, T, on one side of the sun, and at V on the other side.

But this supposition is not true; for the earth revolves in its orbit, A B O, round the sun. Now, if the earth is at A, the time of either conjunction, the planet at this conjunction would appear among the fixed stars at Q, and the arcs of the greatest elongation, Q V and Q T, would be on each side of those stars. But if the earth is at B, at the time of either of the conjunctions, then at the time of this conjunction the planet will appear in the line B S T, and be seen among the fixed stars at T, and the arcs of the greatest elongation will be on each side of these stars; that is, the conjunctions and elongations will happen in a different part of the heavens, when the earth is at B, from what they happen in when the earth is at A. In other respects, the foregoing phenomena will be much the same, notwithstanding the motion of the earth, only the planet will be more direct in the farthest part of the orbit, and less retrograde in the nearest.

The direct and retrograde motion is sometimes swifter, sometimes slower. The direct motion is swiftest, when the sun is between us and the planet; their retrograde swiftest, when they are between us and the sun.

When an inferior planet, viewed from a superior, moves apparently retrograde, the superior planet has also a retrograde motion.

When a superior planet, viewed from an inferior, appears stationary, the inferior planet viewed at the same time from the superior is also stationary.

OTHER APPEARANCES OF THE INFERIOR PLANETS.

The inferior planets, it is plain from what I have shewn you, always appear very near the sun. But, from the motion of the earth, the sun appears in different parts of the heavens at different times of the year; consequently, as the inferior planets are always very near the sun, they will appear in different parts of the heavens at different times of the year; and their conjunctions, &c. will happen sometimes in one part of the heavens, sometimes in another part.

Venus, seen from the earth, appears to vibrate in an arc, half of which is on one side of the sun's apparent place, half on the other.

Venus has been seen sometimes moving across the sun's disk in the form of a round black spot, with an apparent diameter of about 59 seconds.

It has been found by observation, that the orbit of Venus is an ellipse, having the sun in one focus.

The upper apsis of the orbit is called the aphelion, the lower apsis is called the perihelion, of Venus. The line of the apsides has a slow motion eastward, at the rate of 2 degrees, 44 minutes, 46 seconds in a century. The nodes of Venus move westward about 31 seconds in a year.

Venus moves in her orbit, so as to describe round the sun areas proportional to the times.

OF THE PHASES OF VENUS.

That the planets are opake bodies, and shine only by the light they receive from the sun, is plain, because they are not visible in such parts of their orbits as are between the sun and earth, that is, when their illuminated side is turned from us.

The line in the planet's body, which distinguishes the lucid from the obscure part, appears sometimes straight, sometimes crooked. The convex part of the curve is sometimes towards the splendid part, and the concave side towards that which is obscure; and, *vice versa*, according to the situation of the planet with respect to the eye and the sun.

The inferior planets going round the sun in less orbits than our earth does, will sometimes have more, sometimes less of their illuminated side towards us; and as it is the illuminated part only which is visible to us, Mercury and Venus will, through a good telescope, exhibit the several appearances of the moon, from a fine thin crescent to the enlightened hemisphere.

If we view Venus through a telescope, when she follows the sun's rays on the eastern side, and appears above the horizon after sun-set, we shall see her appear nearly round, and but small; she is at that time beyond the sun, and presents to us an enlightened hemisphere. As she departs from the sun, towards the east, she augments in her apparent size; and, on viewing her through a telescope, is seen to alter her figure, abating of her apparent roundness, and appearing successively like the moon in the different stages of her decrease. At length, when she is at her greatest elongation, she is like the moon in her first quarter, and appears as she does when from a full she has decreased to half a moon.

After this, as she approaches, in appearance, to the sun, she appears concave in her illuminated part, as the moon when she forms a crescent; thus she continues, till she is hid entirely in the sun's rays, and presents to us her whole dark hemisphere, as the moon does in her conjunction, no part of the planet being then visible.

When she departs out of the sun's rays on the western side, we see her in the morning, just before day-break. It is in this situation that Venus is called the morning star, as in the other she is called the evening star. She at this time appears very beautiful, like a fine thin crescent: just a verge of silver light is seen on her edge. From this period she grows more and more enlightened every day, till she is arrived at her greatest digression or elongation, when she again appears as a half moon, or as the moon in her first quarter: from this time, if continued to be viewed with a telescope, she is found to be more and more enlightened, though she is all the while decreasing in magnitude, and thus continues growing smaller and rounder, till she is again hid or lost in the sun's rays.

Plate 8, *fig*. 1, represents the orbits of Venus and the earth, with the sun in the center of them. The planet Venus is drawn in eight different situations, with its illuminated hemispheres towards the sun. If we suppose the earth to be at T, when Venus is at A, her dark hemisphere is towards the earth, and she is therefore invisible, except the conjunction happens in her node, for then she appears like a dark spot upon the disk of the sun. When Venus is at B, a little of her enlightened side is turned towards the earth, and therefore she appears sharp-horned; when she is at C, half her enlightened hemisphere is turned towards the earth, and she appears like an half moon; at D, more than half her enlightened hemisphere is towards us, and she appears like the moon about three days before it is full; at E, the whole enlightened hemisphere is towards the earth; Venus is then either behind the sun, or so very near him, that she can hardly be seen; but if she could, she would appear round like the full moon. At F, she is like the moon three days after the full; at G, like a half moon again; at H, like a crescent, with the points of the horns turned the contrary way to what they were at B. All this is equally applicable to Mercury.

Plate 8, *fig.* 2, exhibits the different appearances of Venus, corresponding to her several situations in the foregoing figure; thus, when Venus is at A, *fig.* 1, she is quite dark, as at A, *fig.* 2; when she is at B, *fig.* 1, she appears as at B, *fig.* 2, &c.

The inferior planets do not shine brightest when they are full; thus, Venus does not appear brightest in her superior conjunction, though her illuminated hemisphere be then turned towards us. Her splendor is more diminished by her being at a greater distance from us, than the conspicuous part of her illuminated disk is increased. Dr. *Halley* has shewn, that Venus is brightest when her elongation from the sun is about 40 degrees. Mercury is in his greatest brightness, when very near his utmost elongation.

OF MERCURY.

The planet Mercury resembles Venus in all the circumstances of her apparent motion, and we make similar inferences with respect to the real motions. His orbit is an ellipse, having the sun in one focus. The apsides move eastward 1 degree, 57 minute, 20 seconds in a century; the nodes move westward 45 seconds in a year; and areas are described proportional to the times.

OF THE SUPERIOR PLANETS.

The superior planets exhibit phenomena considerably different from those exhibited by Mercury and Venus.

They come to our meridian both at noon and midnight; when they come to our meridian at noon, and are in the ecliptic, they are never seen crossing the sun's disk.

They are always retrograde when in opposition, and direct when in conjunction.

I have already observed to you, that the greatest elongation of either of the inferior planets is less than 90 degrees, or a quarter of a circle; so that they are never far from the sun, but constantly attend it. But the superior planets do not always accompany the sun, as the inferior ones do: they are indeed sometimes in conjunction with it, but then they are also sometimes in opposition to, or 180° from it.

To be more particular, let S, *plate* 6, *fig.* 3, be the sun; A B C D, the orbit of any superior planet, Mars, for instance; E F G, the earth's orbit. If the earth be at E, the sun at S, and the planet at D, the sun and the planet will be both on the same side of the earth; and, consequently, the planet will appear in conjunction with the sun. But, as the orbit of the earth is between the sun and the orbit of the superior planet, it is possible for the earth to be between the sun and the planet, and consequently for the planet and the sun to be on opposite sides of the earth, or the planet to be in opposition; thus if, when the earth is at E, Mars be at A, he is then in opposition to the sun.

A superior planet is in quadrature with the sun, when its geocentric place is 90° from the geocentric place of the sun; thus, if the earth be at E, and Mars at B or C, he is in quadrature with the sun; for the lines A E, E B, form a right angle, as do also the lines E A, E C.

OF THE DIRECT, STATIONARY, AND RETROGRADE MOTIONS OF THE SUPERIOR PLANETS.

As the earth goes round the sun in less time, and in a less orbit than any of the superior planets, it will not be amiss to suppose a superior planet to stand still in some part of its orbit, while the earth goes once round the sun in hers, and consider the appearances the planets would then have, which are these: 1. While the earth is in her most distant semicircle, the apparent motion of the planet would be direct. 2. While the earth is in her nearest semicircle, the planet would be retrograde. 3. While the earth is near the points of contact of a line drawn from the planet, so as to be a tangent to the earth's orbit, the planet would be stationary.

To illustrate this, let A B C D E F G H, *plate* 7, *fig.* 1, be the orbit of the earth; S, the sun; P Q O V, the orbit of Mars; L M N R T, an arc of the ecliptic. Let us suppose the planet Mars to continue at P, while the earth goes round in her orbit, according to the order of the letters, A B C, &c. A B C D E F G H may be considered as so many stations, from whence an inhabitant of the earth would view Mars at different times of the year; and if straight lines be drawn from each of these stations, through Mars at P, and continued to the ecliptic, they will point out the apparent place of Mars at these different stations.

Thus, supposing the earth at A, the planet will be seen among the stars at L; when the earth has arrived at B, the planet will appear at M; and in the same manner when at C, D, and E, it will be seen among the stars at N, R, T; therefore, while the earth moves over the large part of the orbit, A B C D E, the planet will have an apparent motion from L to T, and this motion is from west to east, or the same way with the earth; and the planet is said to move direct, or according to the order of the signs. When the earth is near to A and E, the point of contact of the tangent to the earth's orbit, the planet will appear stationary for a short space of time.

When the earth moves from E to H, the planet seems to return from T to N; and while it moves from H to A, it will be retrograde to L, where it will again be stationary: and, since the part of the orbit which the earth describes in passing from A to E, is much greater than the part E H P, though the space, T L, which the planet describes in direct and retrograde motion is the same, the direct motion from L to T must be much slower than the retrograde motion from T to L.

When the earth is at C, a line drawn from C through S and P to the ecliptic, shews that Mars is then in conjunction with the sun. But when the earth is at H, a line drawn from H through P, and continued to the ecliptic, would terminate in a point opposite to S; therefore, in this situation Mars would be in opposition to the sun. Thus it appears, that the motion of Mars is direct when in conjunction, and retrograde when in opposition.

The retrograde motions of the superior planets happen oftener the slower their motions are; as the retrograde motions of the inferior planets happen oftener, the swifter their angular motions; because the retrograde motions of the superior planets depend upon the motions of the earth; but those of the inferior, on their own angular motion. A superior one is retrograde once in each revolution of the earth; an inferior one in every revolution of its own.

OTHER PHENOMENA OF THE SUPERIOR PLANETS.

The superior planets are sometimes nearer the earth than at other times; they also appear larger or smaller, according to their different distances from us. Thus, suppose the earth to be at C; if Mars be at V, he is the whole diameter of the earth's orbit nearer to us, than if he were at P, and consequently his disk must appear larger at V, than it would be at P. In other places, the distances of Mars from the earth are intermediate.

The superior planets going round the sun in larger orbits than the earth, turn much the greater part of their enlighted hemisphere towards it, and therefore appear round like the full moon; except Mars, who sometimes appears like the moon at a little distance from the full.

They also move in an ellipse, having the sun in the center; the areas described are proportional to the times.

They are sometimes nearer to, sometimes further from the earth, and their apparent diameter is found to vary according to the difference in their distance.

OF THE SECONDARY PLANETS, OR SATELLITES.

As the moon turns round the earth, enlightening our nights, by reflecting the light she receives from the sun, so do other satellites enlighten the planets to which they belong; and as it keeps company with the earth in its annual revolution round the sun, so do they severally accompany the planets to which they belong in their several courses round that luminary. Jupiter has four satellites, Saturn seven, the Georgium Sidus, from the discoveries of Dr. *Herschel*, six.

The existence of all the satellites, except the moon, would have been unknown to us without the use of the telescope.

The satellites are distinguished, according to their places, into first, second, &c. the first being that which is nearest the planet.

The satellites revolve round their primaries in elliptic orbits, the primary planets being in one of the foci.

The orbits of all Jupiter's satellites are nearly, but not exactly in the same plane, which produced, makes an angle with the plane of Jupiter's orbit of about three degrees. The second deviates a little from the rest.

The planes of the orbits of the secondary planets produced, intersect the heliocentric orbits of their primaries in two opposite points, which are called their nodes. The planes of the orbits of the satellites of Jupiter and Saturn produced, intersect the ecliptic in two opposite points: these points of intersection, to distinguish them from the other, may be called the geocentric nodes of the satellites. The orbits of Jupiter and Saturn are so small in comparison of the sphere of the fixed stars, that the places of their satellites nodes are not sensibly altered by their primaries being in different parts of their orbits.

The orbits of all Saturn's satellites, except the 5th, which deviates from the rest several degrees, are nearly in the same plane. They are nearly parallel to the plane of the equator. The orbit of Saturn's 5th satellite makes an angle with the orbit of his primary of 13° 8′.

A satellite in one of its nodes, seen from its primary, appears in the orbit of its primary: in all other parts of its orbit, it has latitude seen from its primary.

Every circle, whose plane produced passes through the eye, appears a straight line: every circle viewed obliquely will appear an ellipsis, more or less wide, according as the eye is more or less elevated above the plane of the circle. The orbit of a satellite seen from the earth, when its primary's heliocentric place is in his satellites true node, and the earth in its geocentric node, appears a straight line: when the primary is in any other part of his orbit, the satellite's orbit will appear an ellipsis, whose shortest axis increases, the further the primary is from the node of the satellite.

The earth's orbit is so small in comparison of the orbits of Jupiter and Saturn, that whatever part of her orbit the earth is in, when these planets are in their satellites true nodes, their satellites will appear to describe lines very near to straight ones.

When a satellite is in its superior semicircle, *i. e.* that which is furthest from the earth, its geocentric motion is direct; when in its inferior semicircle, *i. e.* that nearest our earth, its geocentric motion is retrograde. Both these motions seem quickest, when the satellite is nearest the center of the primary, and slower when they are more distant; at the greatest distance, they appear stationary for a short time.

Since the distance of Jupiter and Saturn from our earth is very great, and our eye is never elevated much above the planes of its orbit, every satellite of Jupiter or Saturn seen from our earth, will appear always near its primary, and to have an oscillatory motion, sometimes in a straight line, sometimes in an elliptic curve, going from its primary, and returning to it again, first on one side, and then on the other. The satellites of Jupiter or Saturn will sometimes be hid from us by their primary, sometimes pass between us and their primary, and sometimes a satellite will pass between us and another satellite.

The satellites and their primaries mutually eclipse each other, but there are three cases in which the satellites disappear to us.

The one is, when the satellite is directly behind the body of its primary, with respect to the earth; this is called an *occultation* of the satellite.

Another is, when it is directly behind its primary, with respect to the sun, and so falls into its shadow, and suffers an eclipse, as the moon when the earth is interposed between that and the sun.

The last is, when it is interposed between the earth and its primary; for then it cannot be distinguished from the primary itself.

It is not often that a satellite can be discovered upon the disk of Jupiter, even by the best telescopes, excepting at its first entrance, when by reason of its being more directly illuminated by the rays of the sun than the planet itself, it appears like a lucid spot upon it; sometimes, however, a satellite is seen passing over the disk like a dark spot; this has been attributed to spots on the surface of the satellite, and that the more probably, as the satellite has been known to pass over the disk at one time as a dark spot, and at another time to be so luminous as only to be distinguished from the planet at its ingress and egress. The beginnings and endings of these eclipses are easily seen by a telescope, when the planet is in a proper situation; but when it is in conjunction with the sun, the brightness of that luminary renders both the planet and the satellite invisible.

By observing the eclipses of Jupiter's satellites, it was discovered that light was not propagated instantaneously, though it moves with an incredible velocity; so that light reaches from the sun to us in the space of eleven minutes of time, at more than the rate of 100,000 miles in a second.

The orbits of all the satellites of Saturn, except the fifth, are nearly in the same plane, which plane makes an angle with that of Saturn's orbit of about 31°; this inclination is so great, that they cannot pass either across Saturn or behind it, with respect to the earth, except when they are very near their nodes; so that their eclipses are not near so frequent as those of Jupiter. An occultation of the fourth behind the body of Saturn has been observed, and *Cassini* once saw a star covered by the fourth satellite, so that for 13 minutes they appeared as one.

They are so minute as not to be visible, unless the air is exceedingly clear; *Cassini* observed the fifth satellite to diminish in size, as it went through the eastern part of its orbit, until it became quite invisible; while in the western part, it increased in brightness, until it arrived at its greatest splendor. In 1705 it was visible in all parts of its orbit, though the same telescopes were often used before to discover it without success.

The Georgium Sidus is attended by two satellites.*

The following Table shews the general affections of them.

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* The following discoveries respecting this planet and its satellites by Dr. *Herschel*, may be proper to acquaint the reader with, in addition to what I have given in the note to page 34, and the author's annexed table. The reader must observe, that they are the two old satellites "*that move in a retrograde direction.* Whether the motion of the four new ones be direct or retrograde, appears not yet determined."

The two old satellites were formerly found to revolve, the first in 8 days, 17 hours, 1 min. 17 sec. at the distance of 33″ from its primary; the second in 13 d. 11 h. 5 m. 1.5 sec. at the distance of 44.23″. "The new satellites revolve as follow: the periodical times being inferred from their greatest elongations; the interior satellite is 5 d. 21 h. 25 m. at the distance of 25.5″; a satellite intermediate between the two old ones is 10 d. 23 h. 4 m. at the distance of 38.57″; the nearest exterior satellite at about double the distance of the farthest old one, and consequently its periodical time 38 d. 1 h. 49 m. and the most distant satellite full four times as far from its primary as the old second satellite, whence it will take at least 107 d. 16. h. 40 m. to complete its revolution. The disk of the Georgium Sidus he finds to be flattened, and therefore revolves with considerable rapidity on its axis. From the very faint light of the satellites, they are observed to disappear in those parts of their orbits, which bring them apparently nearer to the planet. This does not arise from an atmosphere, for the effect is the same whether the satellite be within or beyond the planet."

His observations were made with reflecting telescopes of 7.10 and 20 feet in length, and powers from 240 to 2400. EDIT.

SECONDARY PLANETS.

		Distance from its Primary. English miles.	Synodical Revolutions round its Primary. Days	Hours	Min.	Sec.	Proportion of bulk with respect to the Earth.
JUPITER's FOUR SATELLITES.	1, or Innermost	269,105	1	18	28	36	$\frac{1}{8}$
	2	428,312	3	13	17	54	$\frac{1}{8}$
	3	683,071	7	3	59	36	About... $\frac{1}{7}$
	4	1,201,386	16	18	5	7	$\frac{1}{3}$
SATURN's SEVEN SATELLITES.	1 discovered in 1789, by Dr. *Herschel.*	126,000	—	22	40	46	
	2	162,000	1	8	53	9	
	3	195,671	1	21	18	27	
	4	250,631	2	17	44	22	
	5	350,099	4	12	25	12	
	6	811,610	15	22	34	38	
	7	2,365,222	79	7	47	—	

Ring of Saturn 21,000 miles broad, and 21,000 miles distant from his Body on all sides. Thickness of the Ring unknown.

GEORGIAN's SATELLITES	1 discovered 11 Jan. 1787, by Dr. *Hersc.*	About 289,118	8	17	1	17	*
	2	387,505	13	11	5	1	

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* For particulars of four others, recently discovered, see the note in the preceding page. Edit.

OF THE MOON'S MOTION.

You have seen, that four of the primary planets are attended in their revolutions by secondary planets; we, as one of these, are attended by the moon, she enlightens our nights, by reflecting the light she receives from the sun, as the other satellites enlighten the planets to which they severally belong.

If you imagine the plane of the moon's orbit to be extended to the sphere of the heaven, it would mark therein a great circle, which may be called the moon's apparent orbit; because the moon appears to the inhabitants of the earth to move in that circle, through the twelve signs of the zodiac, in a periodical month. This position is illustrated by *plate* 9, *fig*. 3; let E F G H I be the orbit of the earth, S the sun, a b c d the orbit of the moon, when the earth is at E: let A B C D be a great circle in the sphere of the heaven, in the same plane with the moon's orbit. The moon, by going round her orbit according to the order of letters, appears to an inhabitant of the earth to go round in the great circle A B C D, according to the order of those letters: for when the moon is at a, seen from the earth at E, she appears at A; when the moon is got to b, she appears at B; when to c, she will appear at C; when arrived at d, she will appear at D. It is true, when the moon is at b, the visual line drawn from E, through the moon, terminates in L; as it does in M, when the moon is at d; but the lines, L M and D B, being parallel, and not farther distant from each other than the distance of the earth's orbit, are as to sense coincident, their distance measured in the sphere of the heaven being insensible; for the same reason, though the earth moves from E to F, in the time that the moon goes round her orbit, so that at the end of a periodical month the moon will be at a, and is seen from the earth at F, in the line F N; the moon will, notwithstanding, appear at A, the lines, F N and E A, being parallel, and as to sense coincident: in like manner, in whatever part of her orbit the earth is, as at H or I, the moon, by going round in her orbit, will appear to an inhabitant of the earth to go round in the great circle A B C D.

The plane of the moon's orbit produced till it cuts the plane of the ecliptic, makes an angle with it of about 5°: this angle is sometimes more, sometimes less than 5°. The points where the moon's orbit produced cuts the ecliptic, are called the moon's nodes; and her ascending ☊ the dragon's head, her descending node ☋ the dragon's tail. The moon's nodes have a slow motion of 19° 22′ in a year, which carries them round the ecliptic, contrary to the order of the signs, in 19 years.

The line of the moon's nodes is a line drawn from one node to the other.

The extremities of the line of the nodes are not always directed to the same point of the ecliptic, but continually shift their places from east to west, or contrary to the order of the signs, performing an entire revolution about the earth, in the space of something less than nineteen years.

The moon appears in the ecliptic only when she is in one of her nodes: in all other parts of her orbit she is either in north or south latitude, sometimes nearer to, sometimes further removed from the ecliptic, according as she happens to be more or less distant from the nodes.

When the place, in which the moon appears to an inhabitant of the earth, is the same with the sun's place, she is said to be in *conjunction*. When the moon's place is opposite to the sun's place, she is said to be in *opposition*. When she is a quarter of a circle distant from the sun, she is said to be in *quad-*

rature. Both the conjunction and opposition of the moon are termed *syzygies.*

The common lunar month, or the time that passes between any new moon and the next that follows it, is called *a synodical month,* or *a lunation.* This month contains 29 days, 12 hours, 44 minutes, 3 seconds.

The moon's motion in her orbit is considered either absolutely, or with relation to the sun. The moon's motion in her orbit, which is also her motion in longitude, is sometimes swifter, sometimes slower; her mean motion is 13 degrees, 10 minutes, 35 seconds, in a day, which carries her round the zodiac in 27 days, 7 hours, 43 minutes. The time wherein the moon is carried round the zodiac is called a *periodical month*; or, a *periodic month* is the time in which the moon performs one entire revolution about the earth, from any point in the zodiac to the same again; and contains 27 days, 7 hours, 43 minutes.

The moon's motion considered with relation to the sun is called her elongation from the sun. The moon's motion from the sun is the excess of the velocity of the moon's motion, above the velocity of the sun's apparent motion in the ecliptic; this excess is sometimes more, sometimes less. The moon's mean motion from the sun is 12 degrees, 11 minutes, 26 seconds in a day, which carries the moon from one conjunction with the sun to another in 29 days, 12 hours, 44 minutes, 3 seconds. The time between any conjunction and the conjunction immediately following, as before observed, is called a synodical month, or a lunation, wherein the moon appears in all her phases.

If the earth had no revolution round the sun, or the sun no apparent motion in the ecliptic, the periodical and synodical month would be the same; but as this is not the case, the moon takes up a longer time to pass from one conjunction to the next, than to describe its whole orbit; or the time between one new moon and the next, is longer than the moon's periodical time.

The moon going round our earth in an orbit, whose semidiameter is less than the nearest distance of any planet, may come between our eye and any planet or star that is near the ecliptic. The time when the moon appears to touch a planet or star, is called its *appulse*, which, being instantaneous, serves to determine the longitude of different places where it is observed.

The moon revolves round the earth from west to east, and the sun apparently revolves round the earth the same way. Now at the new moon, or when the sun and moon are in conjunction, they both set out from the same place, to move the same way round the earth; but the moon moves much faster than the sun, and consequently will overtake it; and when the moon does overtake it, it will be a new moon again. If the sun had no apparent motion in the ecliptic, the moon would come up to it, or be in conjunction again, after it had gone once round in its orbit; but as the sun moves forward in the ecliptic, whilst the moon is going round, the moon must move a little more than once round, before it comes even with the sun, or before it comes to conjunction. Hence it is, that the time between one conjunction, and the next in succession, is something more than the time the moon takes up to go once round its orbit; or a synodical month is longer than a periodical one.

In *plate* 8, *fig*. 3, let S be the sun, C F a part of the earth's orbit, M D a diameter of the moon's orbit when the earth is at A, and m d another diameter parallel to the former, when the earth is at B. Whilst the earth is at A, if the moon be at D, she will be in conjunction; and if the earth was to continue at A, when the moon had gone once round its orbit, from D through M, so as to return to D again, it would again be in conjunction. Therefore, upon the supposition that the earth has no motion in its orbit, the periodical and synodical months would be equal to one another. But as the earth does not continue at A, it will move forward in its orbit, during the revolution of the moon from A to B: and as the moon's orbit moves with it, the diameter, M D, will then be in the position m d; therefore, when the moon has described it's orbit, it will be at d, in this diameter m d; but if the moon is at d, and the sun at S, the moon will not be in conjunction, consequently, the periodical month is completed before the synodical. The moon, in order to come to conjunction, when the earth is at B, must be at e, in the diameter e f; or besides going once round in its orbit, it must also describe the arc d e. The synodical month is, therefore, longer than the periodical, by the time the moon takes up to describe the arc d e.

This may be also explained in another manner, by considering the motion of the sun; a view of the subject, that may render it more easy to some young minds than the foregoing. Thus, let us suppose the earth at rest at E, *plate* 8, *fig.* 4, M the moon in conjunction with the sun at S, while the moon describes her orbit, A B C, about the earth at E, let the sun advance by his apparent annual motion from S to D. It is plain, that the moon will not come in conjunction with the sun again, till, besides describing her orbit, she hath described, over and above that, the arc M F, corresponding to the arc S D.

As the moon goes round the earth in a much smaller orbit than that in which the earth revolves round the sun, sometimes more, sometimes less, and sometimes no part of her enlightened half will be towards us; hence she is incessantly varying her appearance; sometimes she looks full upon us, and her visage is all lustre; sometimes she shews only half her enlightened face; soon she appears as a radiant crescent; in a little time all her brightness vanishes, and she becomes a beamless orb.

The full moon, or opposition, is that state in which her whole disk is enlightened, and we see it all bright, and of a circular figure. The new moon is when she is in conjunction with the sun; in this state, the whole surface turned towards us is dark, and she is therefore invisible to us.

The first quarter of the moon she appears in the form of a semicircle, whose circumference is turned towards the west. At the last quarter, she appears again under the form of a semicircle, but with the circumference turned towards the east.

The moon is generally invisible a day or two before and after conjunction, and the obscure light, visible in the moon a little before and after conjunction, is reflected upon her from the earth.

These phases may be illustrated in a very pleasing manner, by exposing an ivory ball to the sun, in a variety of positions, by which it may present a greater or smaller part of its illuminated surface to the observer. If it be held nearly in opposition, so that the eye of the observer may be almost immediately between it and the sun, the greatest part of the enlightened side will be seen; but if it be moved in a circular orbit, towards the sun, the visible enlightened part will gradually decrease, and at last disappear, when the ball is held directly towards the sun. Or, to apply the experiment more immediately to our purpose; if the ball, at any time when the sun and moon are both visible, be held directly between the eye of the observer and the moon, that part of the ball, on which the sun shines, will appear exactly of the same figure as the moon itself.

The phases of the moon, like those of Venus, may also be illustrated by a diagram; thus in *plate* 9, *fig*. 1, let S be the sun, T the earth, ABCDEFGH the orbit of the moon. The first observation to be deduced from this figure, is, that the half of the earth and moon, which is towards the sun, is wholly enlightened by it; and the other half, which is turned from it, is totally dark. When the moon is in conjunction with the sun at A, her enlightened hemisphere is turned towards the sun, and the dark one towards the earth; in which case, we cannot see her, and it is said to be new moon. When the moon has removed from A to B, a small portion of a b of her enlightened hemisphere will be turned towards the earth; which portion will appear of the form represented at B, *plate* 9, *fig*. 2, a figure which exhibits the phases as they appear to us.

As the moon proceeds in her orbit, according to the order of the letters, more and more of her enlightened part is turned towards the earth. When she arrives at C, in which position she is said to be in quadrature, one half of that part towards the earth is elightened, appearing, as at C, among the phases; this appearance is called a half moon. When she comes to D, the greatest part of that half which is towards us is enlightened; the moon is then said to be gibbous, and of that figure which is seen at D, in *fig*. 2.

When the moon comes to E, she is in opposition to the sun, and consequently turns all her illuminated surface towards the earth, and shines with a full face, for which reason she is called a full moon. As she passes through the other half of her orbit, from E by F, G, and H to A again, she puts on the same phases as before, but in a contrary order or position.

As the moon, by reflected light from the sun, illuminates the earth, so the earth does more than repay her kindness, in enlightening the surface of the moon, by the sun's reflex light, which she diffuses more abundantly upon the moon, than the moon does upon us; for the surface of the earth is considerably greater than that of the moon, and, consequently, if both bodies reflect light in proportion to their size, the earth will reflect much more light upon the moon than it receives from it.

In the new moon, the illuminated side of the earth is fully turned towards the moon, and the Lunarians will have a full earth, as we, in a similar position, have a full moon. And from thence arises that dim light which is observed in the old and new moons, whereby, besides the bright and shining horns, we can perceive the rest of her body behind them, though but dark and obscure. Now, when the moon comes to be in opposition to the sun, the earth, seen from the moon, will appear in conjunction with him, and its dark side will be turned towards the moon, in which position the earth will be invisible to the Lunarians; after this, the earth will appear to them as a crescent. In a word, the earth exhibits the same appearance to the inhabitants of the moon, that the moon does to us.

The moon turns about its own axis in the same time that it moves round the earth; it is on this account that she always presents nearly the same face to us: for by this motion round her axis, she turns just so much of her surface constantly towards us, as by her motion about the earth would be turned from us. This motion about her axis is equable and uniform, but that about the earth is unequal and irregular, as being performed in an ellipsis; consequently, the same precise part of the moon's surface can never be shewn constantly to the earth; which is confirmed by a telescope, by which we often observe a little segment on the eastern and western limb appear and disappear by turns, as if her body librated backwards and forwards; this phenomenon is called the moon's libration. The lunar motions are subject to several other irregularities, which are fully discussed in the larger works on astronomy.*

LECTURE XL.

OF ECLIPSES.

THOSE phenomena, that are termed eclipses, were in former ages beheld with terror and amazement, and looked upon as prodigies that portended calamity and misery to mankind. These fears, and the erroneous opinions which produced them, had their source in the hieroglyphical language of the first inhabitants of the earth. We do not, however, imagine, that even the most ancient of these knew any more of the laws and motions of the heavenly bodies, than what could be discovered from immediate sight; or that they knew enough of the lunar system to calculate an eclipse, or even that they ever attempted it.

The word *eclipse* is derived from the Greek, and signifies dereliction, a fainting away, or swooning. Now, as the moon falls into the shadow of the earth, and is deprived of the sun's enlivening rays, at the time of her greatest brightness, and even appears pale and languid before her obscuration, lunar eclipses were called *lunæ labores,* the struggles or labours of the moon; to relieve her from these imagined distresses, superstition adopted methods as impotent as they were absurd.

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* See a Complete System of Astronomy, by the Rev. *S. Vince,* 4to. EDIT.

When the moon, by passing between us and the sun, deprived the earth of its light and heat, the sun was thought to turn away his face, as if in abhorrence of the crimes of mankind, and to threaten everlasting night and destruction to the world. But thanks to the advancement of science, which, while it has delivered us from the foolish fears and idle apprehensions of the ancients, leaves us in possession of their representative knowledge, enables us to explain the appearances on which it was founded, and points out the perversion and abuse of it.

Any opake body that is exposed to the light of the sun, will cast a shadow behind it. This shadow is a space deprived of light, into which if another body comes, it cannot be seen for want of light; the body, thus falling within the shadow, is said to be eclipsed.

The earth and moon, being opake bodies, and deriving their light from the sun, do each of them cast a shadow behind, or towards the hemisphere opposed to the sun. Now, when either the moon or the earth passes through the other shadow, it is thereby deprived of illumination from the sun, and becomes invisible to a spectator on the body from whence the shadow comes; and such a spectator will observe an eclipse of the body which is passing through the shadow; while a spectator on the body which passes through the shadow, will observe an eclipse of the sun, being deprived of his light.

Hence there must be three bodies concerned in an eclipse; 1. The luminous body; 2. The opake body, that casts the shadow; and 3. The body involved in the shadow.

OF ECLIPSES OF THE MOON.

As the earth is an opake body, enlightened by the sun, it will cast a shadow towards those parts that are opposite to the sun, and the axis of this shadow will alway be in the plane of the ecliptic, because both the sun and the earth are always there.

The sun and the earth are both spherical bodies; if they were, therefore, of an equal size, the shadow of the earth would be cylindrical, as in *plate* 8, *fig*. 5, and would continue of the same breadth at all distances from the earth, and would consequently extend to an infinite distance, so that Mars, Jupiter, or Saturn, might be eclipsed by it; but as these planets are never eclipsed by the earth, this is not the shape of the shadow, and consequently the earth is not equal in size to the sun.

If the sun were less than the earth, the shadow would be wider, the farther it was from the earth, see *plate* 8, *fig*. 6, and would therefore reach to the orbits of Jupiter and Saturn, and eclipse any of these planets when the earth came between the sun and them; but the earth never eclipses them, therefore this is not the shape of its shadow, and consequently the sun is not less than the earth.

As we have proved, that the earth is neither larger nor equal to the sun, we may fairly conclude that it is less; and that the shadow of the earth is a cone, which ends in a point at some distance from the earth, see *plate* 8, *fig*. 7.

The axis of the earth's shadow falls always upon that point of the ecliptic that is opposite to the sun's geocentric place; thus, if the sun be in the first point of Aries, the axis of the earth's shadow will terminate in the first point of Libra. It is clear, therefore, *that there can be no eclipse of the moon but when the earth is interposed between it and the* *sun*, that is, *at the time of its opposition, or when it is full*; for unless it is opposite to the sun, it can never be in the earth's shadow: and if the moon did always move in the plane of the ecliptic, she would every full moon pass through the body of the shadow, and there would be a total eclipse of the moon.

We have already observed, that the moon's orbit is inclined to the plane of the ecliptic, and only coincides with it in two places, which are termed the nodes. It may, therefore, be full moon* without her being in the plane of the ecliptic; she may be either in the north or the south side of it; in either of these cases, she will not enter into the shadow, but be above it in the one, below it in the other.

To illustrate this, let H G, *plate* 10, *fig.* 1, represent the orbit of the moon, E F the plane of the ecliptic, in which the center of the earth's shadow always moves, and N the node of the moon's orbit; A B C D four places of the shadow of the earth in the ecliptic. When the shadow is at A, and the moon at I, there will be no eclipse; when the full moon is nearer the node, as at K, only part of her globe passes through the shadow, and that part becoming dark, it is called a *partial eclipse*; and it is said to be of so many *digits* as there are twelve parts of the moon's diameter darkened. When the full moon is at M, she enters into the shadow C, and passing through it becomes wholly darkened at L, and leaves the shadow at O; as the whole body of the moon is here immersed in the shade, this is called a *total eclipse*. But when the moon's center passes through that of the shadow, which can only happen when she is in the node at N, it is called a *total and central eclipse.* There will always be such eclipses, when the center of the moon, and the axis of the shadow, meet in the nodes.

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* A planet may be in opposition to, or conjunction with, the sun, without being in a right line that passes through the sun and the earth. Astronomers term it in conjunction with the sun, if it be in the same part of the zodiac; in opposition, if it be in a part of the zodiac, 180 degrees from the sun.

The duration of a central eclipse is so long, as to let the moon go the length of three of its diameters totally eclipsed, which stay in the earth's shadow is computed to be about four hours; whereof the moon takes one hour from its beginning to enter the shadow, till quite immersed therein; two hours more she continues totally dark; and the fourth hour is taken up from her first beginning to come out of the shadow, till she is quite out of it.

From the magnitude of the sun, the size of the earth, their distance from each other, the refraction of the atmosphere, and the distance of the moon from the earth, it has been calculated, that the shadow of the earth terminates in a point, which does not reach so far as the moon's orbit. The moon is not, therefore, eclipsed by the shadow of the earth alone. The atmosphere, by refracting some of the rays of the sun, and reflecting others, casts a shadow, though not so dark a one as that which arises from an opake body; when, therefore, we say that the moon is eclipsed, by passing into the shadow of the earth, it is to be understood of the shadow of the earth, together with its atmosphere. Hence it is that the moon is visible in eclipses, the shadow cast by the atmosphere not being so dark as that cast by the earth. The cone of this shadow is larger than the cone of the earth's shadow, the base thereof broader, the axis longer. There have been eclipses of the moon, in which the moon has entirely disappeared: *Hevelius* mentions one of this kind which happened in August 1647, when he was not able to distinguish the place of the moon, even with a good telescope, although the sky was sufficiently clear for him to see the stars of the fifth magnitude.

All opake bodies, when illuminated by the rays of the sun, cast a shadow from them, which is encompassed by a penumbra or thinner shadow, which every where surrounds the former, growing larger and larger as we recede from the body; in other words, the penumbra is all that space surrounding the shadow, into which the rays of light can only come from some part of that half of the globe of the sun, which is turned towards the planet, all the rest being intercepted by the intervening body.

Let S, *plate* 10, *fig.* 2, be the sun, E the planet, then the penumbral cone is F G H. The nearer any part of the penumbra is to the shadow, the less light it receives from the sun; but the further it is, the more it is enlightened; thus, the parts of the penumbra near M are illuminated only by those rays of light, which come from that part of the sun near to I, all the rest being intercepted by the planet E: in like manner, the parts about N can only receive the light that comes from the part of the sun near to L, whereas the parts of the penumbra at P and Q are enlightened in a much greater degree; for the planet intercepts from P only those rays which come from the sun near L, and hides from Q only a small part of the sun near I.

The moon passes through the penumbra before she enters into the shadow of the atmosphere; this causes her gradually to lose her light, which is not sensible at first, but as she goes into the darker part of the penumbra, she grows paler; the penumbra, where it is contiguous to the shadow, is so dark, that it is difficult to distinguish one from the other. If the atmosphere be serene, every eclipse of the moon is visible at the same instant to all the inhabitants of that side of the earth to which she is opposite.

If we imagine a plane parallel to the base of the earth's conical shadow, to pass through ths shadow at the distance of the moon's center from the earth, there will be projected upon the plane the circle of the earth's shadow, surrounded with the circle of the penumbra: the center of those circles is always in the plane of the ecliptic. The circle of the earth's shadow, when the earth is at the same distance from the sun, is greater the nearer the moon is to the earth. The circle of the earth's shadow is greater, when the moon is at the same distance from the earth, the further the earth is from the sun. The apparent semidiameter of the moon in her syzygies is about 15 minutes: the semidiameter of the circle of the earth's shadow is about three times as great as the semidiameter of the moon.

If the moon in opposition be in the node, the eclipse of the moon will be total and central; if very near the node, total, but not central; if so far from the node, that only part falls into the shadow, the eclipse is partial; if so far from the node, that the distance of her center from the center of the circle of the earth's shadow is greater than the semidiameter of the shadow added to the semidiameter of the moon, she will not be eclipsed at all. The moon passes through the penumbra before she falls into the shadow; this makes her gradually lose her light, and grow paler, a little before she begins to be eclipsed.

The moon is sometimes in the middle of a total eclipse invisible in some places, and not in others, because of the different constitution of the air; but generally she appears of a dusky red colour, especially towards the edges, being more dark about the the middle of the shadow: this reddish colour is owing to the rays of the sun, or to the light of sun's atmosphere refracted through the earth's atmosphere, or to the light of the stars and planets; most probably to the first of these.

The sun or moon seen from the earth, or the earth seen from the sun or moon, though spherical, on account of their distance appear like circular planes: these circular planes are called the disks of the sun, earth, or moon. The apparent diameter of the disk of the sun or moon is by astronomers divided into 12 equal parts, which are called digits; each digit into 60 parts, which are called minutes: as many of these digits and minutes as are covered by the shadow in the middle of a partial lunar eclipse, so many digits and minutes of the moon are said to be eclipsed. In a total eclipse of the moon without continuance, the moon is eclipsed 12 digits; in a total eclipse with continuance, she is eclipsed more than 12; thus, if her whole disk is immersed so deep within the shadow, that if her diameter contained 15 such parts as now it contains 12 of, the whole 15 would be eclipsed, the moon is then eclipsed 15 digits. Sometimes the apparent diameter of the moon is observed near the time of the eclipse, and the greatness of the eclipse expressed in minutes of degrees and seconds.

The motion of the moon in her orbit being eastward, the beginning of a lunar eclipse is when the eastern limb or edge of the moon's disk touches the western limb of the shadow; the end of a lunar eclipse, when the western limb of the moon's disk leaves the eastern limb of the shadow; in a total eclipse, the time the whole disk is in the shadow is called the stay, or time of total immersion.

The beginning or end of a lunar eclipse, being instantaneous, serves to discover the longitude, but not accurately without a telescope; for, by reason of the penumbra, the beginning appears too soon, the end too late to the naked eye, and not at the same time to all eyes: for this reason, the longitudes of places, and the places of the moon, determined by eclipses, before the invention of telescopes, cannot be depended upon. The moderns, that they may have a greater number of opportunities of determining the longitude than the beginnings and endings of eclipses would afford, do it by observing the immersions of the most remarkable spots of the moon into the shadow, or by their emerging out of it.

The quantity of a lunar eclipse depends, 1. Upon the largeness of the circle of the earth's shadow, whose diameter may be different. 2. Upon the apparent diameter of the moon, which may be different. 3. *Cæteris paribus*, upon the distance of the moon from her node, at the moment of her being at the full.

The duration of a lunar eclipse depends partly upon its quantity, partly upon the velocity of the moon's motion across the shadow, which is the same as her motion from the sun. The moon's motion from the sun is swiftest when she is in her *perigee*, and the duration of a central eclipse will then be shortest, though the moon's diameter and the diameter of the circle of the earth's shadow be then greatest; because the excess of the moon's way through the shadow is more than compensated by the greater velocity of the moon's motion. The longest duration of a central lunar eclipse, *i. e.* when the earth is in aphelion, and the moon in apogee, is about 3 hours, 57 minutes, 6 seconds. The shortest duration of a central lunar eclipse, *i. e.* when the earth is in perihelion, and the moon in perigee, is 3 hours, 37 minutes, 26 seconds.

OF ECLIPSES OF THE SUN.

The moon, when in conjunction, if near one of her nodes, will be interposed between us and the sun, and will consequently hide the sun, or a part of him, from us, and cast a shadow upon the earth: this is called an *eclipse of the sun*; it may be either partial or total.

An eclipse of any lucid body is a deficiency or diminution of light, which would otherwise come from it to our eye, and is caused by the interposition of some opake body.

The eclipses of the sun and moon, though expressed by the same word, are in nature very different; the sun, in reality, loses nothing of its native lustre in the greatest eclipses, but is all the while incessantly sending forth streams of light every way round him, as copiously as before. Some of these streams are, however, intercepted in their way towards our earth, by the moon coming between the earth and the sun: and the moon having no light of her own, and receiving none from the sun on that half of the globe which is towards our eye, must appear dark, and make so much of the sun's disk appear so, as is hid from us by her interposition.

What is called an eclipse of the sun, is therefore in reality an eclipse of the earth, which is deprived of the sun's light by the moon coming between, and casting a shadow upon it. The earth being a globe, only that half of it which at any time is turned towards the sun, can be enlightened by him at that time; it is upon some part of this enlightened half of the earth, that the moon's shadow or penumbra falls in a solar eclipse.

The sun is always in the plane of the ecliptic; but the moon being inclined to this plane, and only coinciding with it at the nodes, it will not cover either the whole or a part of the sun; or, in other words, the sun will not be eclipsed, unless the moon at that time is in or near one of her nodes.

The moon, however, cannot be directly between the sun and us, unless they are both in the same part of the heavens; that is, unless they are in conjunction. Therefore the sun can never be eclipsed but at the new moon, nor even then, unless the moon at that time is in or near one of her nodes.

The moon being much smaller than the earth, and having a conical shadow, because she is less than the sun, can only cover a small part of the earth by her shadow; though, as we have observed before, the whole body of the moon may be involved in that of the earth. Hence an eclipse of the sun is visible but to a few inhabitants of the earth; whereas an eclipse of the moon may be seen by all those that are on that hemisphere which is turned towards it. In other words, as the moon can never totally eclipse the earth, there will be many parts of the globe that will suffer no eclipse, though the sun be above their horizon.

An eclipse of the sun always begins on the western, and ends on the eastern side; because the moon moving in her orbit from west to east, necessarily first arrives at and touches the sun's western limb, and goes off at the eastern.

It is not necessary, in order to constitute a central eclipse of the sun, that the moon should be exactly in the line of the nodes, at the time of its conjunction; for, it is sufficient to denominate an eclipse of the sun central, that the center of the moon be directly between the center of the sun and the eye of the spectator; for to him, the sun is then centrally eclipsed. But, as the shadow of the moon can cover only a small portion of the earth, it is obvious this may happen when the moon is not in one of her nodes. Further, the sun may be eclipsed centrally, totally, partially, and not at all, at the same time.

A total eclipse of the sun is a very curious spectacle: *Clavius* says that, in that which he observed in Portugal, in 1650, the obscurity was greater, or more sensible than that of the night: the largest stars made their appearance for about a minute or two, and the birds were so terrified, that they fell to the ground.

Thus, in *plate* 10, *fig*. 3, let A B C be the sun, M N the moon, h l g part of the cone of the moon's shadow; f d the penumbra of the moon: from this figure it is easy to perceive,

1. That those parts of the earth that are within the circle represented by g h, are covered by the shadow of the moon, so that no rays can come from any part of the sun into that circle, on account of the interposition of the moon.

2. In those parts of the earth where the penumbra falls, only part of the sun is visible; thus, between d and g, the parts of the sun near C cannot be seen, the rays coming from thence towards d or g being intercepted by the moon: whereas at the same time the parts between f and h are illuminated by rays coming from C, but are deprived by the moon of such as come from A.

3. The nearer any part of the earth, within the penumbra, is to the shadow of the moon, as in places near g, l, or h, the less is the portion of the sun visible to its inhabitants; the nearer it is to the outside of the penumbra, as towards d, e, or f, the greater is the portion seen.

4. Out of the penumbra, the entire disk is visible.

The quantity of a solar eclipse in general is according to the size of the moon's shade projected upon the earth; this shade is largest when the earth is in aphelion, the moon in perigee.

The quantity of a solar eclipse to those within the line, which the center of the moon's shade describes upon the earth, depends upon the apparent diameters of the sun and moon; if they be exactly equal, the eclipse will be barely total; if the diameter of the moon be greater than the sun, it will be more than total; if the diameter of the moon's shade be less than the sun's, the eclipse will be annular, *i. e.* the sun's disk will not be entirely covered, but there will be a ring of his light visible round the disk of the moon.

Eclipses may be also total or annular, in places a little distant from the way of the center of the shade, but not central. More than total eclipses appear greatest in those places, which are nearest the path of the center of the shadow. Partial eclipses appear greatest in those places which are nearest the way of the moon's shadow upon the earth. The quantity of a solar eclipse in any place is estimated by the number of digits of the sun's diameter covered by the disk of the moon, in the middle of the eclipse: in an eclipse barely total, the sun is eclipsed 12 digits: when the eclipse is more than total, he is eclipsed so much more than 12 digits, as the distance between the limbs of the disks of the sun and moon amounts to in those points where those limbs are nearest to each other.

The shape of the moon's shadow projected upon the earth in the middle of the eclipse, depends upon the moon's distance from her node. If the moon is in her node, the centers of the sun, moon, and earth, are all in a straight line, which is perpendicular to the spherical surface of the earth, and therefore the projection of the moon's shadow upon the disk of the earth will be a circle. When the moon has latitude, the axis of her shadowy cone makes an oblique angle to the spherical surface of the earth, and therefore the projection of the shadow upon the earth's disk will be an ellipsis, whose excentricity will be greater, the greater the moon's latitude is.

The largeness of the moon's shade projected upon the earth, depends upon the following circumstances: the conical shadow of the moon is longer, and similar sections at equal distances from the moon are larger, the greater the moon's distance is from the sun. Therefore, the projection of the moon's shadow upon the earth is largest, when the earth is in aphelion and the moon in perigee; least, when the earth is in perihelion and the moon in apogee, at the same time. In a solar eclipse that is central and barely total, the vertex of the moon's shadow does but just reach the surface of the earth; in an annular eclipse, the conical shadow of the moon does not reach so far as the earth.

The way of the moon's shadow upon the earth is generally from west to east; inclining towards the north pole, if the moon is near her ascending node; towards the south pole, if she is near her descending node. The way of the shadow upon the earth may sometimes, but rarely, be from east to west, and the sun appear to be eclipsed first near his eastern limb. The way of the center of the moon's shadow is a straight line, only when it describes a diameter upon the earth's disk; otherwise it is an elliptic curve, but so near a straight line, that it may without any sensible error be represented by one.

The duration of solar eclipses depends on the following considerations. If the moon is in her node, the center of her shadow passes over the center of the earth's enlightened disk, and describes a diameter, *i. e.* the longest line which can be taken in a circle; if the moon has latitude, the center of her shadow describes a chord in the circular disk of the earth, *i. e.* a line less than a diameter.

The whole time the penumbra of the moon is passing over the disk of the earth, is called the time of the general eclipse; because all that time the sun appears eclipsed in some place of the earth or other. The beginning of the general eclipse is when the moon's penumbra enters upon the disk of the earth; the end, when the penumbra of the moon leaves the earth's disk. The duration of the general eclipse depends upon the length of the line described upon the earth's disk by the center of the shadow, the velocity of the moon's motion from the sun, and the largeness and shape of the projection of the shadow and penumbra.

The beginning of a solar eclipse in any place upon the earth, is when the penumbra which surrounds the moon's shadow first touches the place; the end of the eclipse is when the penumbra leaves the place; the duration of the eclipse is whilst the penumbra passes over the place. In any place upon the earth where the eclipse is more than total, the beginning of the total darkness is when the shadow of the moon first touches the place; the end, when it leaves it. Eclipses more than total are said to be total with stay; the time of stay, *viz.* of total darkness, in any place, is the time of the shadow passing over that place.

The time the shadow is passing over any place, (and the same is true of the penumbra, which is always similar to the shadow) is variable, 1st, from the velocity of the moon's motion from the sun; 2d, from the length of a shadow measured in a line parallel to the way of the shadow, and drawn through the place; 3d, from the proximity of the place to the center of the earth's disk.

The circumference of the moon's orbit is 60 times as great as the circumference of the earth; and therefore, each degree of the moon's orbit is equal to 60 degrees of a great circle on the earth's surface. And as one degree of such a circle on the earth contains 69¼ English miles, a degree of the moon's orbit contains 4155 miles. The moon's motion in her orbit, considering it as from the sun to the sun again, or from change to change, is through all the 360 degrees thereof in 29½ days; and therefore she moves about half a degree, or 2077 miles from the sun in one hour; and with the same velocity her shadow moves over the earth, namely, at the rate of $34\frac{6}{10}$ miles in a minute; which is more than four times as swift as the motion of a cannon-ball.

The moon goes round the earth, not in a circular, but in an elliptical orbit; and the earth's center is in one of the foci of that orbit. Hence the moon's distance from the earth is continually varying: at a mean rate it is 240,000 miles.

When the moon changeth at her least distance from the earth, her dark shadow may cover a spot 170 miles broad on the earth's surface, if the time be about noon; but much more if the time be in the morning or evening: and to all who are within that spot, the sun will appear to be totally eclipsed; but to no place without it, although he will be partially eclipsed to several hundred miles around. But, as the moon's motion is then the swiftest that it can be, the dark shadow will be carried quite over that spot in five minutes at most, although the diurnal motion of the earth is the same way the moon's shadow goes; and therefore the longest duration of a total eclipse of the sun can never be more than five minutes, even if it happen at noon. In the morning and evening, the earth's motion contributes very little toward the duration of a solar eclipse, because the dark shadow falls so obliquely on the earth; and indeed, in such an eclipse, the darkness will be over in less than five minutes, although the shadow then covers more of the earth's surface than it can do about noon.

When the moon changeth at her mean distance from the earth, the point of her dark shadow does but just reach the earth: and, to the places where it goes successively over, the sun will be totally eclipsed only for an instant of time.

When the moon changeth at her greatest distance from the earth, her dark shadow does not reach the earth at all: and therefore the sun is not then totally hid from any part of the earth, but appears like a luminous ring, all around the dark body of the moon, to each part of the earth that the point of her shadow is successively directed while she is passing between the earth and the sun.

Thus it is plain, that the sun can never be eclipsed but at the time of new moon, nor the moon but when she is full.

OF THE LIMITS OF SOLAR AND LUNAR ECLIPSES.

The earth goes round the sun every year in an orbit called *the ecliptic*; and therefore the sun, as seen from the earth, appears to go round the ecliptic once a year.

If the moon's orbit lay quite even with the ecliptic, or, as it is commonly expressed, in the plane of the ecliptic, the sun would be eclipsed at the time of every new moon, because the moon would then be directly between the earth and the sun: and the moon would be eclipsed at every time she was full, because the earth would then be directly between her and the sun.

But one half of the moon's orbit lies on the north side of the plane of the ecliptic, and the other half on the south side of it. Therefore the moon's orbit intersets the plane of the ecliptic only in two opposite points, which are called the *moon's nodes*. The angle which the moon's orbit makes with the plane of the ecliptic is 5 degrees, 18 minutes; so that, when the moon is in the northmost point of her orbit, she is 5 degrees, 18 minutes, north of the ecliptic; and as far south of it, when she is in the southmost point of her orbit. Hence it is plain, that the moon can never be in the ecliptic but when she is in one or other of her nodes.

When the moon is any more than 18 degrees from either of her nodes, at the time of her change, she does not pass between the sun and any part of the earth; but goes either above or below the sun, according as she is then north or south of the ecliptic; and therefore she cannot then hide any part of the sun from any part of the earth. But when she changeth within 18 degrees of either node, she will hide the whole or part of the sun from some part of the earth. And if she be in either of her nodes at the time of change, the sun will be centrally eclipsed to that point of the earth's surface which is then in a straight line between the sun's center and the earth's. At all other places, which the center of the moon's shadow goes over, the sun will likewise be centrally eclipsed.

When the moon is any more than 12 degrees from either of her nodes at the time of full, she passeth clear of the earth's shadow; and therefore she cannot be eclipsed at that time. But when she is within 12 degrees of either node, at the time of her being full, she is eclipsed. And when she is full in either of her nodes, she goes through the middle of the earth's shadow, and is totally eclipsed with the longest continuance, which may be above an hour and an half.

OF THE PERIOD OF ECLIPSES.

The ecliptic is divided into twelve equal parts, called *signs*, and each sign into 30 equal parts, called *degrees*. If the moon's nodes had no motion through the signs of the ecliptic, there would be just half a year between the times of the sun's conjunctions with the nodes; and then, in whatever signs the sun and moon were eclipsed in any given year, they would be eclipsed every year after. But the eclipses fall so much sooner every succeeding year than they did on the year before, as to prove, that the nodes move backward, or contrary to the motion of the moon, $19\frac{1}{3}$ degrees every year, from the consequent towards the antecedent signs. And, therefore, they go backwards through all the signs and degrees of the ecliptic in 18 years and 225 days.

If, in that time, there were any exact number of courses of the moon from change to change, without any fraction, there would be an exact period or restitution of eclipses in the same time. But, during this revolution of the nodes, there are 230 courses of the moon, and a quarter of a course more: so that there can be no exact period of eclipses in any complete revolution of the nodes.

But in 18 years, 11 days, 7 hours, and $43\frac{1}{3}$ minutes, in which time there are just 223 courses of the moon, from change to change, there is a conjunction of the sun and moon with the same node as before; and, consequently, a period or restitution of all the eclipses of the sun and moon. And, therefore, if to the mean time of any eclipse, either of the sun or moon, you add 18 years, 11 days, 7 hours, $43\frac{1}{3}$ minutes, you will have the mean time of the return of that eclipse. Only note, that when the last day of February, in leap-year, comes but four times into this period, you are to add the above number of days, hours, and minutes: but when it comes five times in, as it will sometimes do, you must add one whole day less. And thus, any one, who has a set of almanacks for 19 years, in which all the eclipses are noted for that time, may very easily calculate the time of any future eclipse. This is called the *Chaldean Saros*, or period of eclipses.

As the nodes go backwards at the rate of $19\frac{1}{3}$ degrees every year, which, for the sake of round numbers, we may call 19 degrees; these 19 degrees are nearly equal to 19 days of the sun's motion, and the half of 19 is $9\frac{1}{2}$; subtract $9\frac{1}{2}$ days from $182\frac{1}{2}$ days, which make half a year, and there will remain 173 days for the time between the sun's being in conjunction with either of the nodes till the time of his being so with the other.

Now, as the sun can never be eclipsed when he is more than 18 degrees from either node, nor the moon, when she is more than 12, as already mentioned, it is plain, there must be an eclipse of the sun at the time of every new moon that falls within 18 days before or after the time of his being in conjunction with either of the nodes; and that the moon must be eclipsed at every time of her being full within 12 days before or after the time of the sun's being in conjunction with either of the nodes. And, consequently, if we can tell on what days of the year these conjunctions fall, we can easily tell at what new and full moons there must be eclipses; seeing the days of new and full moons are so generally known.

In some years there are six eclipses, four of which are of the sun, and two of the moon: in other years there are only two, and when that happens, they are both of the sun: but the most common number is four; namely, two of the sun, and two of the moon.

THE DARKNESS AT OUR SAVIOUR'S CRUCIFIXION, SUPERNATURAL.

From the account I have given you of eclipses it plainly appears, that the sun can never be eclipsed, in a natural way, but at the time of new moon, nor the moon but when she is full; and that, when the sun is totally eclipsed, the darkness can never continue above five minutes at any place of the earth.

But the three evangelists, St. *Matthew*, St. *Mark*, and St. *Luke*, mention a darkness that continued three hours, at the time of our Saviour's crucifixion. If their account of that darkness had been false, it would have been contradicted by many who were then present; especially as they were great enemies both to Christ and his few disciples, as well as to the doctrine he taught. But as none of the Jews have contradicted the evangelists' account of this most extraordinary phenomenon, it is plain that their account of it is true. Besides, the evangelists must have known full well, that it could not be their interest to palm such a lie upon mankind; which, when detected, must have gone a great way towards destroying the credibility of all the rest of the account they gave of the life, actions, and doctrine of their master: and, instead of forwarding the belief of christianity, it would have been a blow at the very root thereof. We do not find that they have bestowed any panegyric on the life and actions of Christ, or thrown out an invective against his cruel persecutors; but, in the most plain, simple, and artless manner, have told us what their senses convinced them were matters of fact: so that we have as good reason to believe, that there was such darkness, as we have to believe that Christ was then upon the earth: and that he was, has never been contradicted, even by the Jews themselves.

But there are other accounts of Christ, besides those which the evangelists have left us. It is expressly affirmed, by the two Roman historians, *Tacitus* and *Suetonius*, that there was a general expectation spread all over the eastern nations, that out of Judea should arise a person who should be governor of the world. That there lived in Judea, at the time which the gospel relates, such a person as Jesus of Nazareth, is acknowledged by all authors, both Jewish and Pagan, who have written since that time. The star that appeared at his birth, and the journey of the Chaldean wise men, is mentioned by *Chalcidius* the Platonist. *Herod*'s causing the children in Bethlehem to be slain, and a reflexion upon him on that occasion by the emperor *Augustus*, is related by *Macrobius*. Many of the miracles that Jesus wrought, particularly his healing the lame, and curing the blind, and casting out devils, are owned by these inveterate and implacable enemies of christianity, *Celsus* and *Julian*, and the authors of the Jewish Talmud. That the power of the heathen gods ceased, after the coming of Christ, is acknowledged by *Porphyry*, who attributed it to their being angry at the setting up of the christian religion, which he calls impious profane. The crucifixion of Christ under *Pontius Pilate* is related by *Tacitus*, and the earthquake and miraculous darkness attending it were recorded in the public Roman registers, commonly appealed to by the first christian writers, as what could not be denied by the adversaries themselves; and are in a particular manner attested by *Phlegon*, the freed man of *Adrian*.

Some people have said, that the above-mentioned darkness might have been occasioned by a natural eclipse of the sun; and, consequently, that there was nothing miraculous in it. If this had been the case, it is plain, that our Saviour must have been crucified at the time of new moon. But then, in a natural way, the darkness could not possibly have continued for more than five minutes: whereas, to have made it continue for three hours, the moon's motion in her orbit must have been stopped for three hours, and the earth's motion on its axis must have been stopped as long too. And then, if the power of gravitation had not been suspended during all that time, the moon would have fallen a great way towards the earth. So that nothing less than a triple miracle must have been wrought to have caused such a long continued darkness by the interposition of the moon between the sun and any part of the earth: which shews, that they who make such a supposition are entirely ignorant of the nature of eclipses. But there could be no natural or regular eclipse of the sun on the day of Christ's crucifixion, as the moon was full on that day, and, consequently, in the side of the heavens opposite to the sun. And, therefore, the darkness at the time of his crucifixion was quite supernatural.

The Israelites reckoned their months by the course of the moon, and their years, after they left Egypt, by the revolution of the sun, computed from the equal day and night in the spring to the like time again. For we find, they were told by the Almighty, Exod. xii. 2, that the month Abib, or Nisan, should be to them the first month of the year. This was the month in which they were delivered from their Egyptian bondage, and includes part of March and part of April in our way of reckoning.

In several places of the Old Testament, we find, that the Israelites were strictly commanded to kill the paschal lamb on the evening, or, as it is in the Hebrew, between the evenings, of the fourteenth day of the first month; and *Josephus* expressly says, " The passover was kept on the fourteenth day of the month Nisan, according to the moon, when the sun was in Aries." And the sun always enters the sign Aries, when the day and night are equal in the spring season.

They began each month on the first day of the moon's being visible, which could not be in less than twenty-four hours after the time of her change; and the moon is full on the fifteenth day reckoned from the time of change. Hence, the fourteenth day of the month, according to the Israelites' way of reckoning, was the day of full moon: which makes it plain, that the passover was always kept on a full moon day; and at the time of the full moon next after the equal day and night in the spring; or, when the sun was in Aries.

All the four evangelists assure us, that our Saviour was crucified at the time of the passover: and hence it is plane, that the crucifixion was at the time of full moon, when it is impossible that the moon could hide the sun from any part of the earth. St. *John* tells us, that Christ was crucified on the day that the passover was to be eaten; and we likewise find, that some remonstrated against his being crucified "on the feast day, lest it should cause an uproar among the people."*

LECTURE XLI.

OF PARALLAX AND REFRACTION, AND THE ABERRATION OF LIGHT, &c.

ASTRONOMY is subject to many difficulties, besides those which are obvious to every eye. When we look at any star in the heavens, we do not see it in its real place; the rays coming from it, when they pass out of the purer etherial medium, into our coarser and more dense atmosphere, are refracted, or bent in such a manner, as to shew the star higher than it really is. Hence we see all the stars before they rise, and after they set; and never, perhaps, see any one in its true place in the heavens.

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* *Ferguson's* Astronomical Lecture on Eclipses.

There is another difference in the apparent situation of the heavenly bodies, which arises from the stations in which an observer views them. This difference in situation is called the *parallax* of an object.

OF REFRACTION.

As one of the principal objects of astronomy is to fix the situation of the several heavenly bodies, it is necessary, as a first step, to understand the causes which occasion a false appearance of the place of those objects, and make us suppose them in a different situation from that which they really have. Among these causes *refraction* is to be reckoned. By this term is meant, the bending of the rays of light as they pass out of one medium into another.

The earth is every where surrounded by an heterogeneous fluid, a mixture of air, vapour, and terrestrial exhalations, that extend to the regions of the sky. The rays of light from the sun, moon, and stars, in passing to a spectator on the earth, come through this medium, and are so refracted in their passage through it, that their apparent altitude is greater than their true altitude.

Let AC, *plate* 7, *fig*. 3, represent the surface of the earth, T its center, B P a part of the atmosphere, H E K the sphere of the fixed stars, A F the sensible horizon, G a planet, G D a ray of light proceeding from the planet to D, where it enters our atmosphere, and is refracted towards the line D T, which is perpendicular to the surface of the atmosphere; and as the upper air is rarer than that near the earth, the ray is continually entering a denser medium, and is every moment bent towards T, which causes it to describe a curve as DA, and to enter a spectator's eye at A, as if it came from E, a point above G. And as an object always appears in that line in which it enters the eye, the planet will appear at E, higher than its true place, and frequently above the horizon AF, when its true place is below it at G.

This refraction is greatest at the horizon, and decreases very fast as the altitude increases, insomuch that the refraction at the horizon differs from the refraction at a very few degrees above the horizon, by about one-third part of the whole quantity. At the horizon, in this climate, it is found to be about 33 minutes. In climates nearer to the equator, where the air is purer, the refraction is less; and in the colder climates, nearer to the pole, it increases exceedingly, and is a happy provision for lengthening the appearance of the light at those regions so remote from the sun. *Gassendus* relates, that some Hollanders, who wintered in Nova Zembla, in latitude 75 degrees, were agreeably surprized with a sight of the sun seventeen days before they expected him in the horizon. This difference was owing to the refraction of the atmosphere in that latitude. To the same cause, together with the peculiar obliquity of the moon's orbit to the ecliptic, some of these very northern regions are indebted for an uninterrupted light from the moon much more than half the month, and sometimes almost as long as it is capable of affording any light to other parts of the earth.

Through this refraction we are favoured with the sight of the sun, about 3¼ minutes before it rises above the horizon; and also as much every evening after it sets below it, which in one year amounts to more than 40 hours.

It is to this property of refraction that we are also indebted for that enjoyment of light from the sun, when he is below the horizon, which produces the morning and evening twilight. The sun's rays, in falling upon the higher part of the atmosphere, are reflected back to our eyes, and form a faint light, which gradually augments till it becomes day. It is owing to this, that the sun illuminates the whole hemisphere at once; deprived of the atmosphere, he would have yielded no light, but when our eyes were directed towards him; and even when he was in meridian splendor, the heavens would have appeared dark, and as full of stars as on a fine winter's night. The rays of light would have come to us in straight lines, and the appearance and disappearance of the sun would have been instantaneous; we should have had a sudden transition from the brightest sun-shine to the most profound darkness, and from thick darkness to a blaze of light. Thus, by refraction, we are prepared gradually for the light of the sun, the duration of its light is prolonged, and the shades of darkness softened.

To it we must also attribute another curious phenomenon, mentioned by *Pliny*; for he relates, that the moon had been eclipsed once in the west, at the same time that the sun appeared above the horizon in the east. *Mæstlinus*, in *Kepler*, speaks of another instance of the same kind, which fell under his own observation.

OF PARALLAX.

The *parallax* of a celestial object is the difference between the places that the object is referred to in the celestial sphere, when seen at the same time from two different places within that sphere. Or, it may be considered as the angle under which any two places in the inferior orbits are seen, from a superior planet, or from a fixed star.

The parallaxes principally used by astronomy, are those which arise from considering the object as viewed either from the center of the earth and the sun, or from the surface and center of the earth, or from all three compounded.

The difference between the place of any planet as seen from the sun, and the same planet as seen from the earth, is called *the parallax of the annual orbit*; in other words, it is the angle at any planet subtended between the sun and the earth.

The *diurnal parallax* is the change of a celestial body's apparent place, arising from its being viewed from two different stations, one on the surface, and the other at the center of the earth.

The necessity of this distinction is obvious, for you know, that an object will change its apparent situation with respect to another, according to the station from which it is viewed; hence celestial objects, viewed from different parts of the earth's surface, will appear in different situations. To facilitate and give certainty to calculation, astronomers refer all celestial appearances to the center of the earth; of course they are obliged continually to calculate parallaxes, in order to reduce the observed places of the objects to that where they would be situated, if seen from the center of the earth.

Let a line, AB, *plate* 7, *fig*. 4, be drawn perpendicular to the distance B C, between an adjacent object C, and any given station B: the apparent places of the object, when viewed from the extremities of the line AB, will be different.

1. The perpendicular line, AB, is called the base. 2. The extremities, A, B, of the base are called stations. 3. The angle ACB, subtended by the extremities of the base at the object, is called the angle of the parallax. 4. The base is to the lesser of the two distances of the object from the extremities of the base, as the tangent of the angle of parallax to radius; and to the greater, as the sine of the same angle to radius.

Suppose lines to be drawn from the two stations to an object: one of the angles contained by these lines, as in the figure, being a right angle, the other will be the complement of the parallax to 90 degrees.

If the angles at the stations terminating a given base be know, it is easy, by trigonometry, to determine the distance of the object. *N.B.* We here suppose one of the angles at the base to be 90 degrees.

When the distance of an object is greater than 100,000 times the base, the angles at the two stations will not sensibly differ from two right ones; and, consequently, the lines drawn from the object to the stations, are, physically speaking, parallel.

Now the angle, whose tangent is to radius, as 1 to 100,000, is 2006, or very little more than a second; and the most accurate instruments constructed for the mensuration of angles cannot be depended upon to 2 seconds.

Therefore, the parallax of an object, whose distance is above 100,000 times greater than that between the two stations of observation, is insensible.

We may therefore conclude, that if the parallax of an object, observed with an instrument sufficiently exact to measure an angle of 2 seconds, be insensible, the distance of it from either station cannot be less than 100,000 times the base, from the extremities of which it is observed.

But you are to observe, that although the distance of the object cannot be less than 100,000 times the base, it may be greater in any assignable ratio.

Lines drawn from any given point in a base, to an object, may be esteemed in practice parallel, without sensible error, if the distance of the object is more than 100,000 times the base.

Having laid down these few general principles, we may now proceed to explain the parallaxes used by astronomers, which are principally those which arise from considering the object as viewed from the center of the earth and sun, from the surface and the center of the earth, and from these compounded.

The diameter of the earth is the longest straight line we can accurately obtain, and is in general the base used for determining the distances of celestial objects by their parallaxes.

The change in the apparent place of a planet, or fixed star, or any celestial body arising from its being viewed on the surface, or from the center of the earth, is called its diurnal parallax.

To explain the parallaxes with respect to the earth, I shall use the diagram, *plate* 7, *fig.* 2, where H S W represents the earth; T its center; O R G part of the moon's orbit; P r g a part of the planet's orbit; Z *a* A part of the starry heavens; Z S a line which passes through the zenith.

Now it is plain, from the inspection of the diagram, that a planet, P, situated in the zenith line, always answers to the same point of the heaven, whether it be regarded from the center T, or from the point, S, on the surface: *so that a celestial body in the zenith has no parallax.*

If the planet, instead of being in the zenith, is in the horizontal line SA, perpendicular to the line Z S, its distance, T, from the center of the earth is the same as its distance T P. But the place of the planet, seen from the center of the earth, is at *d*, while its place seen from S, or the surface, is at A; the difference between these two situations is their parallax.

Let us now compare these two points or situations with the point Z, where the planet is seen, when in the zenith of the observer. The angle Z S *g*, formed by the vertical line S Z, and the line S A, in which the planet appears, is the apparent distance of the planet from the zenith: but if you were at the center of the earth, the angle, Z T *g*, would shew the true distance from the zenith.

The apparent distance, Z S *g*, is greater than the true distance Z T *g*, in the right angled triangle *g* T S. Geometry proves, that the angle, Z S *g*, is equal to the two angles S T *g*, S *g* T. It is therefore greater than the angle S T *g*, by the quantity S *g* T. Thus the apparent distance of the planet from the zenith, is greater than the true distance; and the difference between these two angles S *g* T, is the parallactic angle, which is in this case called the horizontal parallax, the line S T being the base.

The parallax of a celestial body is then the angle formed from the center of the body by two lines, one of which proceeds to the center of the earth, the other to its surface; or it is the inclination of two lines which proceed the one from the center, the other from the surface of the earth, to unite in the center of the planet; or still, in other words, it is the angle at which the semidiameter of the earth will appear, seen from the center of the planet.

The triangle, T S *g*, is called the parallactic triangle; it is always situated vertically, because the line, S T, is a vertical line; thus the whole effect of parallax is made in a vertical circle; indeed, as the center of the earth is under your feet, that is the plane of all the vertical circles. Therefore, parallax is always reckoned on these circles, making them appear lower, but never to the right or left of a vertical circle; consequently, the parallax does not change the azimuth of a planet.

I have hitherto only spoken of the parallax when the planet is in the horizon, that is, when Z S *g* is a right angle, and I have called this the horizontal parallax. If the planet is nearer the zenith, as at γ, the parallactic angle becomes smaller, and is called the parallax of altitude. It is evident by the diagram, that the horizontal parallax is the greatest of all, and that as the planet rises above the horizon, it gradually diminishes until it comes to the zenith, where it vanishes, or becomes equal to nothing. Thus the parallax, A G D, of the object G, is greater than the parallax, a R B, of the same object when at R; but when it is at O, in the zenith, there is no parallax.

The parallax of a planet is smaller in proportion as it is more distant; for the nearer *g* is to S, the greater is the angle S *g* T; hence mathematicians prove, that when the altitudes are the same, the parallax of altitude is in the inverse ratio of the distance.

The horizontal parallax of the moon, which is the greatest of all the planets, does not exceed a degree.

The parallax of a planet increases also with its apparent diameter; in fact, the further a planet is off, the less is its apparent diameter, and the diameter diminishes like the parallax in an inverse ratio of the distance; therefore the parallax is as the diameter. If the parallax was lessened one half, the diameter would be one half less; and the same relation subsists, whatever be the distance. Thus, the diameter of the moon is always $\frac{6}{11}$ of its parallax, and the cube of this fraction $\frac{1}{46}$, marks its size with respect to the earth.

When the horizontal parallax of a celestial object is known, it is easy to discover, by the rules of trigonometry, the distance of the object; for in the right angled triangle S T G, you have the semidiameter of the earth, S T, known, the angle, S T D, 90 degrees, and the parallactic angle, T G S, given, from whence it is easy to obtain the rest. It is, indeed, difficult to determine the horizontal parallax with accuracy, on account of the effects of refraction. But the parallax of an object at any altitude being observed, its horizontal parallax may be computed.

The diurnal parallax of an object according to the different situation of the ecliptic and equator in respect to the zenith, will sometimes cause an apparent change or parallax of the latitude, longitude, declination, and right ascension thereof.

In finding the parallax of the sun, or, which is the same, the angle under which the earth's semidiameter would appear at that distance, the angle is so exceeding small, that a mistake of one second would occasion an error of about seven millions of miles; from whence you may judge the exactness necessary in finding the parallax of any celestial object.

The annual parallax is the change in the apparent place of an object, which is caused by its being viewed from the earth in different parts of its orbit.

The annual parallax of all the planets is very considerable, that of the fixed stars insensible.

The sun's parallax being so small as to be scarcely sensible to the best observers, when using the most accurate instruments, various indirect methods have been proposed: of these, that suggested by Dr. *Halley* is allowed to be the most perfect. It was to observe the transit or passage of Venus over the sun's disk; a phenomenon which happened in the years 1761 and 1769, and by which this difficult problem was resolved with an accuracy unlooked for by astronomers of ancient times.

OF THE APPARENT MOTION OF THE FIXED STARS, OCCASIONED BY THE ABERRATION OF LIGHT.

The astronomers of the last century, in their endeavours to discover the parallax of the fixed stars, found annual variations in the stars, following a law contrary to what would have happened, had it arisen merely from the earth's situation in his orbit.

These variations threw them into great perplexity, from which they were not relieved till Dr. *Bradley*, by applying himself to observe accurately these variations, at last discovered the true cause thereof; and has given rules for calculating the changes, and shewn what allowances are to be made in consequence thereof, in observations of the stars.

He has also proved clearly, that this aberration of the fixed stars, or the motion which makes them appear to describe ellipses of 40 seconds diameter, arises from the motion of light combined with the annual motion of the earth.

This I shall now endeavour to explain, and place in as clear a point of view as possible, desiring you only to recollect the idea of the decomposition of forces into parallelograms, as explained in our Lectures on Mechanics. Let E, *plate* 15, *fig.* 1, be a star darting a ray of light, which I shall consider here as a single particle, going from E to B. Let AB be a small portion of the earth's orbit, of 20 seconds, for example; and C B the space that the ray of light has passed through, while the earth moved from A to B; thus, the particle was at C, when the earth was at A, and arrives at B the same time as the earth. Hence C B and AB express the velocity of light and the earth during 20 seconds.

Draw C D parallel to A B, and finish the parallelogram D B A; now, according to the known principle of the composition and decomposition of forces, we may consider the velocity, E B, of the light, as resulting from the two velocities in the directions C D, C A; the velocity, C D, being the same in quantity and direction as the velocity, A D, of the earth, cannot be perceived, is therefore destroyed with respect to us; the eye cannot see by a ray moving in the same direction and with the same velocity as the eye. So that the only part, C A, of the velocity of the light will subsist to us, and the ray will come to the eye in the direction C A, and we shall perceive the star in the line A C, or, according to B D, which is parallel thereto; the angle, C B D, is what is termed the *aberration*; it is the quantity that a star appears out of its true place, in consequence of the motion of light and the earth.

Perhaps another way of considering this may render it more clear to your apprehensions. Suppose a tube to be erected perpendicular to the horizon at a time when it rains, the drops to fall in a perpendicular direction, and the tube to be of such a diameter as to admit but one drop at a time; now it is plain, that if a drop of water enter the orifice of the tube, it will fall down without touching the sides. But if the tube be moved along, still preserving its perpendicular direction, any drop that enters the tube will strike against the sides, and none could pass freely through while the tube is in motion, unless the tube has such a direction as will compensate the motion.

Thus, let A B, *plate* 15, *fig.* 2, represent the horizon, C D the perpendicular tube, and G D the course of a drop of rain; then, if C D be moved towards A, while the drop is falling within the tube, it is evident, that the inner surface of the tube, which is situated towards B, will be carried against the drop, and prevent its arriving at the bottom without touching. But if the inclined tube be moved with a similar motion to that of the drop from E to D, in the same time that the drop moves from C to D, the lower orifice of the tube and the drop will be found at the same instant at D, and the velocity of the drop will be expressed by C D, and that of the tube by E D.

The same reasoning holds good, if instead of drops of rain we suppose particles of light, and a telescope instead of a tube. For to an observer, who, through the tube C D, views the vastly distant object C, if the motion of light be instantaneous or infinitely swift, no finite motion of C D, its position being unaltered, can prevent its being visible; because by the supposition the light, which enters at C, will arrive at D before C D can have moved at all.

But if light be propagated in time, and the observer be carried by a motion similar as to acceleration to that of light, the tube must be inclined in an angle, whose sine is to the sine of C E D, as the velocity of the observer is to the velocity of light.

By this theory, which is established by numerous observations of stars of different magnitudes and situations, it appears, that the small apparent motion, which the fixed stars have about their real places, which is called their aberration, arises from the proportion which the velocity of the earth's motion in her orbit bears to that of light.

This proportion is found to be as 10210 to 1; from whence it follows, that light moves or is propagated from the sun to the earth, in 8 seconds, 12 thirds.

This discovery of the aberration of light by Dr. *Bradley*, is a direct proof of the motion of the earth in its orbit. The motion of light, combined with the motion of the earth, produces an apparent difference in the places of the fixed stars; and as this motion is found to affect all the stars differently, according to their situations, it fully proves the truth of the cause upon which they were supposed to depend, and shews that the Copernican system is conformable to the nature and order of things.

OF THE PRECESSION OF THE EQUINOXES.

The stars, which compose the constellations, are found to increase their longitude continually. The whole starry firmament appears to have a slow motion, from west to east, about the poles of the ecliptic, so that the constellations seem to have deserted the places first appropriated to them; insomuch that the first star in the constellation of Aries, which appeared in the vernal intersection of the equator and ecliptic in the time of *Meton*, the Athenian, upwards of 1900 years ago, is now removed above 30 degrees from that point; so that Aries is now where Taurus was, Taurus where Gemini was, &c. The discovery of this motion is due to *Hipparchus* of Rhodes, one of the most celebrated astronomers of ancient times.

Hence the constellations on the zodiac of a celestial globe, do not agree in figure and character, the signs or constellations of the zodiac being to the east of those signs, or arcs of the ecliptic, which are called by the same names; for, in order to avoid confusion, astronomers thought proper to let the several portions of the ecliptic, where those constellations were first observed to be, retain their old names, consequently, the vernal equinox is still considered as the first point of Aries.

The spaces formerly occupied by the zodiacal constellations, retaining their ancient names, are called *anastra*, or *without their former stars*; whereas the spaces they now possess are called *stellata*.

This slow motion of the stars forwards, is really caused by a like slow motion of the equinoctial points backwards; and this is owing to the revolution of the axis of the equator about the axis of the ecliptic; the pole of the equator describing in the heavens a circle about the pole of the ecliptic.

By this precession of the equinoctial points from east to west, they meet the sun every year 50 seconds of longitude before a complete revolution has been made. The time, in which the sun appears to revolve from tropic to tropic, is called a *tropical year*; this, with the time he has yet further to go to complete the revolution, namely, 50 seconds, is called the *siderial year*. Sir *Isacc Newton* attributes this motion to the spheroidal figure of the earth, deducing from this figure the revolution of the poles of the world round those of the ecliptic.

This motion carries the stars about 1 degree, 20 minutes, 23 seconds, in 100 years; so that the total revolution of the fixed stars eastward, back to the equinoctial points again, will be completed in 25972 years.

LECTURE LXII.

OF SOLAR AND SIDERIAL DAYS; OF MEAN TIME; THE EQUATION OF TIME, &c.

THE rotation of the earth about its axis being uniform, it necessarily follows, that the apparent diurnal revolution of the stars about the earth must be also uniform, that is, made in equal times; they therefore will form a very proper measure to denote time. But then, as they turn successively with a constant motion, one must be selected, by whose revolutions time may be measured; we must also fix a term from whence to commence our reckoning.

The sun being the most conspicuous object, was fixed upon by the astronomers of early ages, as the most proper measure for the parts of time. But when more accurate observations were made, the sun's motion was found not to be uniform, and consequently the time measured thereby would be neither regular nor equal; they were therefore obliged to find out a mean or regular time for the basis of their calculations.

An astronomical or solar day is divided into 24 hours, reckoning them in numeral succession, from 1 to 24. The first twelve hours are sometimes distinguished by the mark P. M. for after noon; the other twelve are distinguished by A. M. for before noon. Astronomers generally reckon through the 24 hours from noon to noon; and what is by the common way of reckoning called morning hours, is by them reckoned in succession from noon to midnight. Thus 5 o'clock in the morning of April the 10th, is by astronomers called April 9, 17 hours.

If the sun had no other apparent motion but that of its diurnal revolution, it would every day describe the same parallel, and be accompanied by the same stars. But it has also an apparent annual motion, by which it seems to be carried through the zodiac every year, from west to east, that is, in a direction contrary to that of its diurnal revolution.

Hence, if on any day the sun and a star pass the meridian at the same instant, on the next day when the star returns to the meridian, the sun will have departed towards the west, as much space as in that interval it has passed over by its annual motion, and will therefore arrive at the meridian some moments after the star; the day following it will be still later, so that at the end of six months, it passes 12 hours after the star, which has therefore gained 12 hours on the sun; and at the end of the year the star will have passed 366 times over the meridian, where the sun has only passed 365 times.

In this view we have considered the sun's apparent motion; the result is the same if you consider the earth's real motion. If, indeed, the earth had no real motion, and consequently the sun no apparent motion, the length of a natural day would be about 23 hours 56 minutes, for in that time a revolution of the earth is completed, as appears by an easy observation; for any fixed star that is on the meridian at a given hour of night, will, after 23 hours 56 minutes, be on the meridian again the night following. This interval of time is called a *siderial day*.

Thus you see that there is a distinction between a solar day and a siderial day.

A solar or astronomical day is the space of time that intervenes between the sun's departing from any one meridian, and its return to the same again. The *siderial day* is the space of time that elapses between the departure of a star from a given meridian, and its return to the same again.

I shall now endeavour to shew you, why these days differ in length; that is, why the sun takes up more time to complete one revolution than a star.

This difference arises from the sun's annual motion. The sun does not continue always in the same place in the heaven, as the fixed stars do: but if it is seen at M, *plate* 4 *fig*. 2, one day, near the fixed star R, it will have shifted its place the next day, and will be near to some other fixed star L. This motion of the sun is from west to east, and one entire revolution is completed in a year. Suppose, therefore, that the sun, when it is at M, near to the fixed star R, appears in the south of any particular place, S; and then imagine the earth to turn once round upon its axis from west to east, or in the direction S T V W, so that the place may be returned to the same situation. After this rotation is completed, the star, R, will be in the south of the place as before; but the sun having, in the mean time, moved eastwards, and being near to the star L, or to the east of R, will not be in the south of the place S, but to the eastward of it: upon this account the place, S, must move on a little further, and must come to T before it will be even with the sun again, or before the sun will appear exactly in the south.

This may be illustrated by an instance: the two hands of a watch are close together, or even with one another at twelve; they both turn round the same way, but the minute hand turns round in a shorter time than the hour hand; when the minute hand has completed one rotation, and is come round to twelve, the hour hand will be before it, or will be at one; so that the minute hand must move more than once round, in order to overtake the hour hand, and be even with it again.

As this subject is of some importance, we shall endeavour to render it more clear, by placing it in a different point of view.

The diameter of the earth's orbit is but a physical point, in proportion to the distance of the stars; for which reason, and the earth's uniform motion on its axis, any given meridian will revolve from any star to the same star again, in every absolute turn of the earth upon its axis, without the least perceptible difference of time being shewn by a clock which goes exactly true.

If the earth had only a diurnal, without an annual motion, any given meridian would revolve from the sun to the sun again, in the same quantity of time as from any star to the same star again; because the sun would never change his place with respect to the stars. But, as the earth advances almost a degree eastward in its orbit, in the time that it turns eastward round its axis, whatever star passes over the meridian on any day with the sun, will pass over the same meridian on the next day, when the sun is almost a degree short of it, that is, 3 minutes 56 seconds sooner. If the year contained only 360 days, the sun's apparent place, so far as his motion is equable, would change a degree every day, and then the siderial days would be just four minutes shorter than the solar.

Let ABCDEFGH, *plate* 4, *fig*. 3, be the earth's orbit, in which it goes round the sun every year, according to the order of the letters, that is, from west to east, and turns round its axis the same way, from the sun to the sun again, in every 24 hours. Let S be the sun and R a fixed star, at such an immense distance, that the diameter, G C, of the earth's orbit bears no sensible proportion to that distance; N m n, the earth in different points of its orbit. Let N m be any particular meridian of the earth, and N a given point or place lying under that meridian.

When the earth is at A, the sun S hides the star R, which would always be hid if the earth never moved from A; and, consequently, as the earth turns round its axis, the point N would always come round to the sun and the star at the same time.

But, when the earth has advanced through an eighth part of its orbit, or from A to B, its motion round its axis will bring the point N an eighth part of a day, or three hours, sooner to the star than to the sun. For the star will come to the meridian in the same time as though the earth had continued in its former situation at A, but the point N must revolve from N to n, before it can have the sun upon its meridian. The arc, N n, being therefore the same part of a whole circle, as the arc A B, it is plain, that any star which comes to the meridian at noon with the sun, when the earth is at A, will come to it at nine o'clock in the forenoon, when the earth is at B.

When the earth has passed from A to C, one-fourth part of its orbit, the point, N, will have the star upon its meridian, or at six in the morning, six hours sooner than it comes round to the sun; but the point, N, must revolve six hours more, before it has mid-day by the sun: for now the angle, A S C, is a right angle, and so is N C n; that is, the earth has advanced 90 degrees on its axis, to carry the point N from the star to the sun; for the star always comes to the meridian, when N m is parallel to R S A; because C S is but a point in respect to R S. When the earth is at D, the star comes to the meridian at three in the morning at E, the earth having gone half round its orbit; N points to the star at midnight, it being then directly opposite to the sun; and, therefore, by the earth's diurnal motion, the star comes to the meridian twelve hours before the sun; and then goes on, till at A it comes to the meridian with the sun again.

Thus it is plain, that one absolute revolution of the earth on its axis, which is always completed when any particular star comes to be parallel to its situation at any time of the day before, never brings the same meridian round from the sun to the sun again; but that the earth requires as much more than one turn on its axis, to finish a natural day, as it has gone forward in that time, which at a mean state; is a 365th part of a circle, that is 59 minutes 8 seconds; for, as 365 days are to 1 day, so are 360 degrees to 59 minutes 8 seconds. Hence, in 365 days the earth turns 366 times round its axis, and consequently, as one revolution of the earth on its axis completes a siderial day, there must be one more siderial day in a year than there are solar days.

OF MEAN AND APPARENT TIME.

Further and more accurate observations shewed, that the solar days were not equal to each other; after investigating this subject, astronomers were under the necessity of distinguishing two sorts of time, one they called *true and apparent time,* the other *mean time.*

True and apparent time is determined by the interval between the sun's center passing the meridian, and that of his next return to the same meridian. it is that shewn by a sun-dial, which marks the hours every day in such a manner, that every hour is a 24th part of the time between the noon of that day and the noon of the day immediately following.

Mean time is that shewn by a clock, which goes uniformly.

The time shewn by a sun-dial, and the mean time, or that shewn by a well-regulated clock, agree only four times in the year, on the 15th of April, the 16th of June, the 31st of August, and the 24th of December.

The clock, if it goes equably and true all the year round, will be before the sun from the 24th of December to the 15th of April; from that time, to the 16th of June, the sun will be before the clock; from thence, to the 31st of August, the clock will be again before the sun; and from the 31st of August to the 24th of December, the sun will be faster than the clock. On any other day, if you would set a clock by a sun-dial, you must make use of an equation table, which shews, for every day in the year, how many minutes or seconds the sun is before or behind the clock: the difference between the sun and the clock is called the *equation of time.**

Both the solar and mean day are divided into 24 hours, or 86400 seconds.

Three hundred and sixty degrees of the equator pass under the meridian in a mean day and 59 minutes 8 seconds, which is that part of 360 degrees of the sun's annual motion corresponding to the time of a mean day.

In a solar or true day, the 360 degrees of the equator pass under the meridian and an arc thereof answering to the ecliptic arc described the same day, called the sun's motion in right ascension.

When the sun is furthest from the earth or in apogee, his motion in right ascension in a day, is 1 degree, 2 minutes, 6 seconds; therefore 361 degrees, 2 minutes, 6 seconds, pass the meridian in a solar day. By working this proportion, as 360 degrees, 59 minutes, 8 seconds, is to 24 hours, so is 361 degrees, 2 minutes, 6 seconds, we find 24 degrees, 0 minutes, 12 seconds. Consequently, when the sun is in apogee, the solar day is 12 seconds longer than the mean day. From hence it follows:

1. That in every second of a clock well-regulated to mean time, an arc of 15 minutes 28 seconds of

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* See my pamphlet "Methods of finding a true Meridian Line, for placing Sun Dials, setting Clocks," &c. Edit.

the equator passes the meridian; for this is the quotient of 360 degrees, 59 minutes, 8 seconds, divided by 86400 seconds.

2. That a star's revolution answers to 360 degrees of the equator, while the mean day answers to 360 degrees, 59 minutes, 8 seconds. This difference of 59 minutes, 8 seconds, being reduced to time, gives 3 minutes, 56 seconds: therefore, the stars anticipate 3 minutes 56 seconds, every day on mean time; or, which is the same thing, a star's diurnal revolution is made in 23 hours, 56 minutes, 4 seconds.

3. To find whether a clock be well regulated to mean time, observe if it shew exactly 23 hours, 56 minutes, 4 seconds, from the instant of any star's passage through a fixed point, to that of its return to the same point. By what the clock exceeds this, it is faster, by what it wants thereof, it is slower than mean time.

OF THE EQUATION OF TIME.

I have already observed to you, that the *equation of time* is the difference between mean and apparent time, or that pointed out by a good clock and a sundial.

You will soon perceive that there would have been no difference, and consequently no need for any equation, 1st, if the earth's orbit was a perfect circle with the sun at the center; 2dly, if the earth had moved through an equal part or portion of that circle every day; and 3dly, if the axis of her diurnal motion was always perpendicular to the plane of her orbit. But neither of the foregoing suppositions is true; for, 1. the orbit of the earth is an ellipse; 2. her motion therein is not equal; and 3. her axis is inclined to the plane of her orbit: the measure of time therefore, as far as it depends on these circumstances, must be unequal and subject to an equation.

The equation of time may then be considered as arising, 1. from the obliquity of the ecliptic to the equator; 2. from the unequal progression of the earth through her elliptic orbit.

Of the first cause of inequality, or that arising from the obliquity of the earth to the ecliptic. The motion of the earth on its axis is perfectly equable, or always at the same rate; and, the plane of the equator being perpendicular to its axis, it is evident, that in equal times equal portions of the equator would pass over the meridian; and so also would equal portions of the ecliptic, if it were either parallel to, or coincident with the equator.

But, as the ecliptic is oblique to the equator, the equable motion of the earth carries unequal portions of the ecliptic over the meridian in equal times, the difference being proportionate to the obliquity; and, as some parts of the ecliptic are more oblique than others, those differences are unequal among themselves. If, therefore, we should suppose two suns to start from the beginning either of Aries or Libra, and continue to move through equal arcs in equal times, one in the equator, the other in the ecliptic, the equatorial sun would always return to the meridian in 24 hours time as measured by a good clock, but the sun in the ecliptic would return to the meridian sometimes sooner, sometimes later, than the equatorial sun, and only the same instant with him four days in the year.

To render this plainer, we will have recourse to a diagram, *plate* 4, *fig.* 4. This figure is to be considered as a view of part of the concave sphere of the heaven, wherein D E represents a part of the celestial equator, F G a part of the ecliptic, A the intersection of the two circles at the vernal equinox, A B a degree upon the equator. If we imagine the plane of the meridian to pass from the situation M M, into the situation N N, in going through the arc AB, one degree of the equator, it will also go through the arc, AC, more than one degree of the ecliptic. For in the triangle A B C, the angle, at B, is a right one, consequently, the hypothenuse, AC, is the longest side.

At the solstices the obliquity of the ecliptic has a contrary effect, and helps to lengthen the natural days: this will be easily comprehended by viewing the diagram, *plate 4*, *fig.* 5, where T T is part of the tropic of Capricorn, C D part of the ecliptic, which may be considered as coincident with the tropic for some distance on each side of the solstitial point, as from A to B; and therefore meridians, which are perpendicular to the tropies, may be considered for that space as perpendicular to the ecliptic. This being supposed, a meridian, in going from A towards B, will go through as large an arc in the tropic as the ecliptic: but the tropic not being a great circle, any arc, as a b, taken in both these circles, will measure more minutes in the tropic than in the ecliptic, and that in the ratio as the ecliptic exceeds the tropic in dimensions: now, the circumference of the ecliptic is to that of the tropic, nearly as 60 to 55: and therefore the arc a b, of 55 minutes in the ecliptic, will be 60 minutes in the tropic. But every meridian passes in the same time through similar arcs in the celestial equator, and all circles parallel to the equator, as the tropic's arc: consequently, at the solstices every arc of the ecliptic passed through by any meridian in a given time, will be to the arc of the equator passed through in the same time, as 55 to 60.

The second cause of the difference in the time shewn by a well-regulated clock, and a true sun-dial, arises from the inequality of the sun's apparent motion, which is slowest in summer, when the sun is farthest from the earth, and swiftest in the winter, when he is nearest thereto; whereas the earth's motion on its axis is equable all the year round.

If the sun's apparent motion in the ecliptic were equable, the whole difference between the equal time as shewn by the clock, and the unequal time as shewn by the sun, would arise from the obliquity of the ecliptic. But this is not the case, for the sun's motion sometimes exceeds a degree in 24 hours, though it is generally less. And when his motion is slowest any particular meridian will return and revolve sooner to him than when his motion is quickest, for it will overtake him in less time when he advances through a less space, than when he moves through a larger one.

On the 1st of January, the daily motion of the sun in the ecliptic is nearly 1 degree, 1 minute, 13 seconds; but on the 1st of July, the daily motion is 57 minutes, 13 seconds; the medium of these is 59 minutes, 13 seconds. The sun's place in the ecliptic, calculated on the supposition of a daily motion of 59 minutes, 13 seconds, will be behind his observed place from the beginning of January to the beginning of July, and will be before it from the beginning of July to the beginning of January; the greatest difference is about 1 degree, 55 minutes, 32 seconds, which is observed about the beginning of April and October, at which time the observed daily motion is 59 minutes, 13 seconds.

It is necessary for an astronomer to know both true and mean time; the first, to ascertain the time of observation; the second, because the tables of the planets, &c. are calculated in conformity thereto.

The relation between true and mean time is discovered by observing the time marked by your clock, at the instant when the center of the sun passes the meridian, and adding what it wants of 12 hours, or subtracting the excess above it.

It is obtained for any other hour besides 12, by taking from the difference between the time it has passed on two subsequent days, the part proportional to the hour you are seeking.

Example: March 3, when the sun's center passed the meridian, the clock was 12 hours, 17 minutes, 49 seconds; the clock was therefore 17 minutes, 49 seconds, faster than true or apparent time.

On the 4th of March, it was 12 hours, 17 minutes, 42 seconds; the difference is 6½ seconds, or about one-fourth of a second per hour. Now on the 3d, the planet Mars passed the meridian at 14 hours, 27 minutes, 32 seconds; the pendulum was 3½ seconds more advanced than at noon, which gives its advance for that hour, 17 minutes, 45½ seconds, which, subtracted from 14 hours, 27 minutes, 32 seconds, gives 14 hours, 9 minutes, 46½ seconds, for the true or apparent time of the transit of Mars.

From what I have now explained to you, it appears, that there is no body in nature, whose motion is perfectly uniform and regular; that whenever we look for commensurabilities and equalities in nature, we are always disappointed. The earth is spherical, but not perfectly so; the summer is unequal when compared with the winter; the ecliptic disagrees with the equator, and never cuts it twice in the same equinoctial point, the orbit of the earth has an eccentricity, more than double in proportion to the spheroidity of its globe; no number of the revolutions of the moon coincide with any number of the revolutions of the earth in its orbit; no two of the planets measure one another; and thus it is wherever we turn our thoughts, so different are the views of the Creator from our narrow conception of things; where we look for commensuration, we find variety and infinity.*

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* *Jones's* Physiological Disquisitions.

It is scarce possible to refrain here from joining with an elegant moralist in observing, that all the appearances of nature uniformly conspire to remind us of the lapse of time, and the flux of life. The day and night succeed each other, the rotation of the seasons diversifies the year, the sun attains the meridian, declines and sets, and the moon every night changes its form.

The day may be considered as an image of the year, and a year as the representation of life. The morning answers to the spring, and the spring to childhood and youth; the noon corresponds to the summer, and the summer to the strength of manhood; the evening is an emblem of autumn, and autumn of declining life. The night, with its silence and darkness shews the winter, in which all the powers of vegetation are benumbed; and the winter points out the time when life shall cease, with its hopes and pleasures.

He that is carried forward, however swiftly, by a motion equable and easy, perceives not the change of place, but by the variation of objects. If the wheel of life, which rolls thus silently along, passed on through undistinguishable uniformity, we should never mark its approaches to the end of the course. If one hour were like another; if the passage of the sun did not shew its wasting; if the changes of the seasons did not impress upon us the flight of the year; quantities of duration, equal to days and years, would glide away unobserved. If the parts of time were not variously coloured, we should never discern their departure or succession; but should live thoughtless of the past, and careless of the future, without will, and perhaps without power, to compare the time which is already lost, with that which may probably remain.

LECTURE XLIII.

ON THE PLANETARIUM, TELLURIAN, AND LUNARIUM.

To represent by machines the motions and various aspects of the heavenly bodies, the parallelism of the earth's axis, together with its annual and diurnal motions, and by these means to explain the beautiful variety of seasons, and other terrestrial and celestial phenomena, has ever been considered as one of the noblest efforts of mechanical genius. Among the variety of machines contrived for these purposes, that before you, and its parts, *plate* 11, *fig.* 1, and *plate* 12, *fig.* 1 and 2, is the best adapted for representing the celestial motions.

It seems highly probable, that the ancients were not unacquainted with planetary machines, but that the same powers of genius, which led them to contemplate and reason upon the heavenly bodies, induced them to realize their ideas, and form instruments for explaining them; and we may fairly presume, that these were carried to no small degree of perfection, when we consider, that of one *Archimedes* was the maker, and *Cicero* the encomiast.

A planetarium may be considered in some sort as a diametrical section of our universe, in which the upper and lower hemispheres are suppressed.

The upper plate is to answer for the ecliptic; on this are placed, in two opposite, but corresponding circles, the days of the month, and the signs of the ecliptic, with their respective characters; by this plate you may set the planetary balls so as to be in their respective places in the ecliptic, for any day in the year.

Through the center of this plate, you observe a strong stem, on which is a brass ball to represent the sun; round the stem are differert sockets to carry the arms, by which the several planets are supported. The planets are represented by ivory balls, having the hemisphere which is next the sun white, the other black, to exhibit their respective phases. I can with ease either take off, or put on, any of the planets, as occasion may require. About the primary planets are placed the secondary planets or moons, which are in this instrument only moveable by the hand.

I turn the handle, and all the planets are put in motion, moving round that ball which represents the sun. Now, if you take the earth's motion as a standard, they move with the same relative velocities and periodical times that they have in the heavens. I scarcely need observe, that it is impossible to give an idea of the proportion and distances of the planets in the compass of an instrument so small as that before you, or indeed of any instrument whatsoever.

The motions are carried on by a train of wheel-work concealed in the brass box, ABC, under the ecliptic.*

GENERAL EXPLANATION OF THE SOLAR SYSTEM, BY THE PLANETARIUM.

As the center of the solar system is the only place from which the motion of the planets can be truly seen, let us suppose ourselves situated at the center of the ball representing the sun. In this situation the heavens would appear perfectly spherical, the stars being so many lucid points in the concave surface of the sphere.

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* This complete instrument was contrived by the late Mr. *B. Martin*; as it, in my opinion, deserves a fuller explanation, I shall give one in my Appendix to this Lecture. EDIT.

Having attentively considered the stars for a long time, you will remark two sorts, the one scattered throughout the heavens unequally luminous, perfectly at rest, and therefore called *fixed stars*; the other sort, moving round the sun with unequal velocities, called *planets*. By taking one of the fixed stars for a point to set out from. or for this purpose in our instrument, using any of the points into which the ecliptic is divided, it will be easy to determine the motions of the planets.

Thus by observing the earth as I turn the winch, you may perceive, that it continually approaches nearer and nearer to the more eastern signs; in a certain space of time, it will return to the place from whence it set out.

Thus you see how readily the periods of the planets revolutions may be obtained, by observing the time that elapses between their setting out from any fixed point, and returning to the same again. The annual motion of the earth is the basis or standard, to which the motions of the other planets are compared; and this is one of the reasons, why the months and days of our months are engraved on the ecliptic circle of the planetarium.

The curves, which the planets describe in their revolutions, are what are called their *orbits*.

If the paths of the planets were in one place, as in this instrument, they would all be referred to one circle in the heavens; but this is not the case, for their paths cross each other in different parts of the heavens.

When you consider the motions of the little system before you, while you are supposed to view it from the sun, all is regular; but when you view it from the earth, many of the appearances become intricate and perplexed. When the works of God are examined from a proper point, there is nothing but uniformity, beauty, and precision, and the heavens present you with a plan inexpressibly magnificent, and yet regular beyond the power of invention. When properly examined and looked into, you will always find the volume of the universe as perfect as its Author, containing mines of truth for ever opening, fountains of good for ever flowing, being an endless succession of brighter and still brighter exhibitions of the glorious Godhead, always answering the nature and idea of infinite fulness and perfection.

In the center of the system is the sun, placed in the heavens by that Almighty Power, who said, "Let there be light, and there was light," to be the fountain of light and heat to all the planets revolving round him. In this machine, his situation is pointed out by this brass ball.

The nearest planet to the sun is *Mercury*; observe the part of the ecliptic he is at, and also the place where the earth is situated. I now turn the handle, Mercury is arrived at the place from whence he set out, and our earth has gone over 88 days of the ecliptic; the velocity we here give the planet is inconsiderable, but in his course in the heavens he is supposed to move with a velocity equal to 100,000 miles in an hour.

Venus is the next planet in the system; in the heavens she is distinguished by the superiority of her lustre, appearing to us the brightest and largest of all the planets. By observing her course through the ecliptic, and comparing it with the days passed over by the earth at the same time, you will find, in our instrument, Venus revolving round the sun in 225 days; in the heavens she moves at the rate of 80,955 miles in an hour.

The third planet in the solar system is the *Earth*; diminutive as it appears before you in this instrument, its real diameter is near 800 miles; it revolves round the sun in the space of 365 days, into which number the brazen ecliptic is divided; this revolution constitutes our year, while its revolution round its axis forms day and night.

The little ball, close and annexed to the earth, represents the *Moon*, of which I shall say nothing at present, as there is a part of the instrument for explaining more particularly her phenomena.

The planet *Mars* is the next in order, being the first above the earth's orbit; he revolves round the sun in about 686 days; so that our earth, as you will observe by the instrument, goes nearly twice round, while he is performing his revolution; he is supposed to move at the rate of 55,783 miles in an hour. To this planet our earth and moon will appear like two moons, sometimes half or three quarters illuminated, but never full.

Jupiter, the largest of all the planets, is next beyond Mars; and our earth must have gone nearly twelve times round the ecliptic for one revolution of Jupiter; yet so far is its path removed from the sun, that to go round it in this space of time, it moves at the rate of 30,193 miles an hour. Though larger than the earth, it appears but small in the heavens, because, as you know, objects decrease in their apparent magnitude in proportion to their real distance. It is attended by four satellites, here represented by these four balls; they are invisible to the naked eye, but appear beautiful through a telescope.

Saturn, the next planet, is still higher in the system, performing its circuit in about thirty years of our time; so that in this instrument its motion is scarcely sensible, while in the heavens it goes at the rate of 22,298 mile an hour, it is accompanied by five satellites, and a large luminous ring, here represented by this ivory circle, and which is one of the most curious phenomena of nature.

The *Georgium Sidus*, or Georgian planet, so called in compliment to his Majesty, King George the Third, the Royal patron and promoter of the arts and sciences, is the seventh planet in our system; it is near twice the distance of Saturn from the sun, round which it revolves in about eighty years. Dr. *Herschel* has discovered six satellites to this planet.

To explain, by the planetarium, why the sun, being a fixed body, appears to pass through all the signs of the zodiac in one year: also shewing, that this phenomenon is occasioned by the annual motion of the earth.

As the general phenomena of the planetary system will be the best understood by an induction of particulars, I shall remove all the planets but those whose motion I am going to explain; for instance, I shall leave only the earth and sun, and place the earth over Libra, and it is plain, that the sun will then be transferred by the eye of a spectator on the earth to Aries, in which sign it will appear at the latter end of March: move the earth on its orbit to Capricorn, and the sun will appear at Cancer in June, seeming to have moved from ♈ to ♋, though it has not stirred, the real motion of the earth having caused the spectator to transfer the sun to all the intermediate points in the heavens, and thus given it an apparent motion. Continue to move the earth till it arrives at Aries, and the sun will be seen in Libra in the month of September: moving the earth on to Cancer, the visual ray of the spectator refers the sun to Capricorn, as it appears in the month of December. Lastly, continue moving the earth, and it will arrive at Aries, where we set out. Thus I have shewn, that it is the motion of the earth which causes the sun to appear in all the different signs of the zodiac. Custom, indeed, has taught us to say, *the sun is in Aries,* when it is between us and Aries, and so of any other sign; whereas it would have been more proper to say, that the *earth is in Libra.*

To shew why, at different times of the year, we see the heavens decorated with an entire different collection of stars.

This phenomenon is occasioned by the earth's progressive or annual motion: while the earth is traversing its course under the vast concave of fixed stars, we are gradually carried under the different constellations. From hence it is evident, that at night, when the earth is turned from the sun, we shall in succession have the opportunity of viewing from time to time all the stars in the zodiac, and consequently a different constellation will present itself every month.

Thus, the Pleiades in Taurus are not visible in the summer; but in the winter the earth is between the sun and them. These stars are observable at night, because they are not intercepted from our sight by the sun's rays; and in this manner they appear during the whole winter, only they seem to get more westerly every night, as the earth moves gradually by them to the east. To make this more clear, place the earth in the planetarium between the sun and any of the signs, that side towards the sun will be day, and that towards the sign night: it follows, that at night we are turned towards the stars, which in that sign (suppose, as before, the Pleiades in Taurus) will then be conspicuous to us; but as the spring approaches, the earth withdraws itself from between the sun and the Pleiades, till at length, by its progressive motion, it gets the sun between it and them, which then lie hid behind the solar rays: after the same manner, while the earth performs its annual tract, the sun, which always seems to move the contrary way, effaces, by his splendor, the other constellations successively; but the stars opposite to those hid by the sun, are at night presented to our view.

GENERAL PHENOMENA OF THE PLANETS.

I shall now place the earth, Mars, and Venus, on the planetarium, and as each planet moves with a different degree of velocity, they are continually changing their relative positions. Thus, on turning the handle of the machine, you find, 1st. That the earth moves twice as fast as Mars, making two revolutions while he makes one; and Venus, on the other hand, moves much faster than the earth. Secondly, that in each revolution of the earth, these planets continually change their relative positions, corresponding sometimes with the same point of the ecliptic, but much oftener with different points.

To explain the conjunction, opposition, elongation, and other phenomena of the inferior planets.

We may now proceed to make some observations on the motions of Venus, as observed in the planetarium. If considered, as viewed from the sun, we shall find, that Venus would appear at one time nearer to the earth than at another; that sometimes she would appear in the same part of the heavens, and at others in opposite parts thereof.

As the planets, when seen from the sun, change their position with respect to the earth, so do they also, when seen from the earth, change their position with respect to the sun, being sometimes nearer to, at others farther from, and at other times in conjunction with him.

But the conjunctions of Venus or Mercury, seen from the earth, not only happen when they are seen together from the sun, but also when they appear to the solar spectator to be in opposition. To illustrate this, bring the earth and Venus to the first point of Capricorn; then by applying a string from the sun over Venus and the earth, you will find them to be in conjunction, or on the same point of the ecliptic.

Whereas, if you turn the handle till the sun is between Venus and the earth, a spectator in the sun will see Venus and the earth in opposition; but an inhabitant of the earth will see Venus not in opposition to the sun, but in conjunction with him.

In the first conjunction, Venus is between the sun and earth; this is called the inferior conjunction. In the second, the sun is situated between the earth and Venus; this is called the superior conjunction.

After either of these conjunctions, Venus will be seen to recede daily from the sun, but never departing beyond certain bounds, never appearing opposite to the sun; and when she is seen at the greatest distance from him, a line joining her center with the center of the earth, will be a tangent to the orbit of Venus.

To illustrate this, I take off the sun from its support, and the ball of Venus from its supporting stem, and place this wire, *plate* 11, *fig*. 2, so that one part, P, may be on the stem that supports the earth, and a similar socket, *fig*. 3, on the pin which supports the ball of Venus; the wire, F, is to lie in a notch at the top of the socket, which has been put upon the supporting stem of Venus: then will the wire represent a visual ray going from an inhabitant of the earth to Venus. By turning the handle, you will now find that the planet never departs further than certain limits from the sun, which are called its greatest elongations, when the wire becomes a tangent to the orbit; after which it approaches the sun, till it arrives at either the inferior or superior conjunction.

It is also evident from the instrument, that Venus, from her superior conjunction, when she is furthest from the earth, to the time of her inferior conjunction, when she is nearest, sets later than the sun, is seen after sun-set, and is, as it were, the forerunner of night and darkness. But from the inferior conjunction, till she comes to the superior one, she is always seen westward of the sun, and must consequently set before him in the evening, and rise before him in the morning, foretelling that light and day are at hand.

Bring Venus and the earth to the beginning of Aries, when they will be in conjunction; and turn the handle for nearly 225 days, and as Venus moves faster than the earth, she will arrive at Aries, and have finished her course, but will not have overtaken the earth, who has moved on in the mean time; and Venus must go on for some time, in order to overtake her. Therefore, if Venus should be this day in conjunction with the sun, in the inferior part of her orbit, she will not come again to the same conjunction till after 1 year, 7 months, and 12 days.

It is plain, by inspection of the planetarium, that though Venus does always keep nearly at the same distance from the sun, yet she is continually changing her distance from the earth; her distance is greatest when she is in her superior, and least when she is in her inferior conjunction.

To explain the phases, the retrograde, direct, and stationary situations of the planets.

As Venus is an opake globe, and only shines by the light she receives from the sun, that face which is turned towards the sun will always be bright, while the opposite one will be in darkness; consequently, if the situation of the earth be such, that the dark side of Venus be turned towards us, she will then be invisible, except she appear like a spot on the disk of the sun. If her whole illuminated face is turned towards the earth, as it is in her superior conjunction, she appears of a circular form; and, according to the different positions of the earth and Venus, she will have different forms, and appear with different phases, undergoing the same changes of form as the moon. These different phases are seen very plain in this instrument, as the side of the planet which is opposite to the sun is blackened; so that in any position, a line drawn from the earth to the planet, will represent that part of her disk which is visible to us.

The irregularities in the apparent motions of the planets, is a subject that this instrument will fully elucidate; and the pupil will find that they are only apparent, taking their rise from the situation and motion of the observer. To illustrate this, let us suppose the fore-mentioned wire, when connected with Venus and the earth, to be the visual ray of an observer on the earth; it will then point out how the motions of Venus appear in the heavens, and the path she appears to us to describe among the fixed stars.

Let Venus be placed near her superior conjunction, and the instrument in motion, the wire will mark out the apparent motion of Venus in the ecliptic. Thus Venus will appear to move eastward in the ecliptic, till the wire becomes a tangent to the orbit of Venus, in which situation she will appear to us to be stationary, or not to advance at all among the fixed stars; a circumstance which is exceeding clear and visible upon the planetarium.

Continue turning, till Venus be in her superior conjunction, and you will find by the wire or visual ray that she now appears to move backward in the ecliptic, or from east to west, till she is arrived at that part where the visual ray again becomes a tangent to her orbit. In which position, Venus will again appear stationary for some time: after which she will commence anew her direct motion.

Hence, when Venus is in the superior part of her orbit, she is always seen to move directly, according to the order of the signs; but when she is in the inferior part, she appears to move in a contrary direction.

What has been said concerning the motions of Venus is applicable to those of Mercury; but the conjunctions of Mercury with the sun, as well as the times of his being direct, stationary, ar retrograde, are more frequent than those of Venus.

OF THE SUPERIOR PLANETS, AS SEEN FROM THE EARTH.

If you extend your observations on the instrument to Mars, you will find by the visual ray that Mars, when in conjunction and when in opposition, will appear in the same point of the ecliptic, whether it is seen from the sun or the earth; and in this situation only is its real and apparent place the same, because then only the ray proceeds as if it came from the center of the universe.

You will find, that the direct motion of a superior planet is swifter the nearer it is to the conjunction, and slower when it is nearer to quadrature with the sun; but that the retrograde motion of a superior planet is swifter the nearer it is to opposition, and slower the nearer it is to quadrature; but at the time of change from direct to retrograde, its motion becomes insensible.

TO PROVE BY THE PLANETARIUM THE TRUTH OF THE COPERNICAN, AND ABSURDITY OF THE PTOLEMAIC SYSTEM.

Of all the prejudices which philosophy contradicts, there is none so general as that the earth keeps its place unmoved. This opinion seems to be universal, till it is corrected by instruction, or by philosophical speculation. Those who have any tincture of education, are not now in danger of being held by it; but yet they find at first a reluctance to believe that there are antipodes, that the earth is spherical, and turns round its axis every day, and round the sun every year. They can recollect the time when reason struggled with prejudice upon these points, and prevailed at length, but not without some efforts.*

The planetarium gives ocular demonstration of the motion of the earth about the sun, by shewing that it is thus only that the celestial phenomena can be explained, and making the absurdity of the Ptolemaic system evident to the senses of young people. For this purpose, I take off the brass ball which represents the sun, and put on a small ivory ball, *fig.* b, in its place to represent the earth, and place a small brass ball, *fig.* a, for the sun, on that arm which carries the earth.

The instrument in this state will give an idea of the Ptolemaic system, with the earth immoveable in the center, and the heavenly bodies revolving about it in the following order: Mercury, Venus, *the Sun*, Mars, Jupiter, and Saturn. Now, in this disposition of the planets, several circumstances are to be observed, that are contrary to the real appearances of the celestial motions, and which therefore prove the falsity of this system.

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* *Reid's* Essays on the Intellectual Powers of Man.

It will appear from the instrument, that on this hypothesis Mercury and Venus could never be seen to go behind the sun, from the earth, because the orbits of both of them are contained between the sun and the earth; but these planets are seen to go as often behind the sun as before it; we may, therefore, from hence conclude that this system is erroneous.

It is also apparent in the planetarium, that on this scheme these planets might be seen in conjunction with, or in opposition to the sun, or at any distance from it. But this is contrary to experience; for they are never seen in opposition to the sun, or on the meridian of London, for instance, at midnight; nor do they ever recede from the sun beyond certain limits.

Again, on the Ptolemaic system all the planets would be at an equal distance from the earth, in all parts of their orbits, and would therefore necessarily appear always of the same magnitude, and moving with equal and uniform velocities in one direction; circumstances which are known to be repugnant to observation and experience.

To rectify the planetarium, or place the planets in their true situations, as seen from the sun.

The situations of the planets in the heavens are accurately calculated by astronomers, and published in almanacks appropriated to the purpose, as the Nautical Almanack, *White*'s Ephemeris, &c. An ephemeris is a diary or daily register of the motions and places of the heavenly bodies, shewing the situation of each planet at 12 o'clock each day. These situations it exhibits both as seen from the sun, and from the earth; but, as the former, or the heliocentric, is the only one of any use for this purpose, I shall here explain so much of that part of Mr. *White*'s

Ephemeris, for the year 1790, as will enable you to rectify the planetarium.

Days.	Day increa	Length of Day	Helioc. long. ♄	Helioc. long. ♃	Helioc. long. ♂	Helioc. long. ⊕	Helioc. long. ♀	Helioc. long. ☿
1	7 4	14 48	27 ♓ 35	2 ♍ 14	27 ♍ 16	11 ♏ 14	8 ♐ 35	1 ♉ 18
7	7 24	15 8	27 47	2 42	29 57	17 2	18 7	26 ♊ 53
13	7 44	15 28	27 59	3 0	2 ♎ 39	21 52	7 37	3 ♌ 4
19	8 0	15 44	28 11	3 37	5 20	28 36	7 ♑ 7	4 ♍ 15
25	8 10	16 0	28 23	4 5	8 3	4 ♐ 22	16 36	0 ♎ 0

In the foregoing table for May, 1790, you have the heliocentric places calculated to every six days of the month, which is sufficiently accurate for general purposes. Thus, on the 19th, you have Saturn in 28° 11′ of Pisces, Jupiter in 3° 37′ of Virgo, Mars in 5° 20′ of Libra, the Earth 28° 36′ of Virgo, Venus 7° 7′ of Capricorn, and Mercury 4° 13′ of Virgo; to which places on the ecliptic of the planetarium, the several planets are to be set, and they will then exhibit their real situations, both with respect to the sun and the earth for that day.

To use the instrument as a tellurian, plate 12, *fig.* 1.

The sun, the earth, and the moon, are bodies, which, from our connexion with them, are so interesting to us, that it is necessary to enter into a minute detail of their respective phenomena. To render this instrument a tellurian, all the planets are first to be taken off, the piece of wheel-work, A B, is to be placed on in their stead, in such a manner that the wheel, c, may fall into the teeth that are cut upon the edge of the ecliptic. The milled nut, D, is then to be screwed on, to keep the wheel-work firmly in its place. It is best to place this wheel-work in such a manner, that the index, E, may point to the 21st of June, and then to move the globe, so that the north pole may be turned towards the sun.

The instrument will then shew, in an accurate and clear manner, all the phenomena arising from the annual and diurnal motion of the earth: as the globe is of three inches diameter, all the continents, seas, kingdoms, &c. may be distinctly seen; the equator, the ecliptic, tropics, and other circles, are very visible, so that the problems relative to peculiar places may be satisfactorily solved. The axis of the earth is inclined to the ecliptic in an angle of 66½ degrees, and preserves its parallelism during the whole of its revolution. About the globe there is a circle to represent the terminator, or boundary between light and darkness, dividing the enlightened from the dark hemisphere. At N O is an hour circle, to determine the time of sun rising or setting.

The brass index, G, represents a central solar ray; it serves to shew when it is noon, or when the sun is upon the meridian at any given place: it also shews what sign and degree of the ecliptic on the globe the sun describes on any day, and the parallel it describes.

The plane of the terminator, H I, passes through the center of the earth, and is perpendicular to the central solar ray. The index, E, points out the sun's place in the ecliptic of the instrument for any given day in the year.

To explain the changes of seasons by the tellurian.

The first thing to be done, is to rectify the tellurian; or, in other words, to put the globe into a position similar to that of the earth for any given day. Thus, to rectify the tellurian for the 21st of June, turn the handle till the annual index comes to the given day; then move the globe by the arm K L, so that the north pole may be turned towards the sun; and adjust the terminator, so that it may just touch the edge of the arctic circle. The globe is then in the situation of the earth for the longest day in our northern hemisphere, the annual index pointing to the first point of Cancer and the 21st of June; bring the meridian of London to coincide with the central solar ray G, and move the hour circle, N O, till the index L, points to XII; we then have the situation of London with respect to the longest day.

Now, on gently turning the handle of the machine, the point representing London will, by the rotation of the earth, be carried away towards the east, while the sun seems to move westward; and when London has arrived at the eastern part of the terminator, the index will point on the hour circle the time of sun-setting for that day; continue to turn on, and London will move in the shaded part of the earth, on the other side of the terminator; when the index is again at XII, it is midnight at London: by moving on, London will emerge from the western side of the terminator, and the index will point out the time of sun-rising, the sun at that instant appearing to rise above the horizon in the east to an inhabitant of London.

It will be evident by the instrument, while in this position, that the central solar ray, during the whole revolution of the earth on its axis, only points to the tropic of Cancer, and that the sun is vertical to no other part of the earth, but those which are under this tropic.

By observing how the terminator cuts the several parallels of the globe, we shall find that all those between the northern and southern polar circles, except the equator, are divided unequally into diurnal and nocturnal arcs, the former being greatest on the north side of the equator, and the latter on the south side of it.

In this position the northern polar circle is wholly on that side the terminator which is nearest the sun, and therefore altogether in the enlightened hemisphere, and the inhabitants thereof enjoy a continual day. In the same manner, the inhabitants of the southern polar circle continue in the dark at this time, notwithstanding the diurnal revolution of the earth; it is the annual motion only which can relieve them from this situation of perpetual darkness, and bring to them the blessings of day and the enjoyments of summer. While in this state, the inhabitants in north latitude are nearest to the central solar ray, and consequently to the sun's perpendicular beams; and of course, a greater number of his rays will fall upon any given place, than at any other time: the sun's rays do now also pass through a less quantity of the atmosphere, which, together with the length of the day and the shortness of the night, are the reasons of the increase of the heat in summer, together with all its other delightful effects; the season when the Lord pours forth his blessings upon every living creature in the greatest abundance.

While the earth continues to turn round on its axis once a day, it is continually advancing from west to east, according to the order of the signs, as is seen by the progress of the annual index, E, which points successively to all the signs and degrees of the ecliptic; the sun in the mean time seems to describe the ecliptic also, going from west to east, at the distance of six signs from the earth; that is, when the earth really sets out from the first point of Capricorn, the sun seems to set out from the first point of Cancer, as is plain in the index.

But as, during the annual revolution of the earth, the axis always remains parallel to itself, the situation of this axis with respect to the sun must be continually changing.

As the earth moves on in the ecliptic, the northern polar circle gets gradually under the terminator; so that when the earth is arrived at the first point of Aries, and the annual index is at the first point of Libra, on the 22d of September, this circle is divided into two equal parts by the terminator, as is also every other parallel circle, and consequently the diurnal and nocturnal arcs are equal: this is called the time of equinox; the days and nights are then equal all over the earth, being each of them twelve hours long, as will be seen by the horary index, L. The central solar ray, G, having successively pointed to all the parallels that may be supposed to be between the equator and the tropic of Cancer, is at this period perpendicular to the inhabitants that live at the equator.

By continuing to turn the handle, the earth advances in the ecliptic, and the terminator shews how the days are continually decreasing, and the diurnal arcs shortening: till by degrees the whole space contained by the northern polar circle is on that side of the terminator which is opposite to the sun, which happens when the earth has got to the first point of Cancer, and the annual index is at the first point of Capricorn, on the 21st of December. In this state of the globe, the northern polar circle, and all the country within that space, have no day at all; whilst the inhabitants that live within the southern polar circle, being on that side of the terminator which is next the sun, enjoy perpetual day. By this, and the former situation of the earth, you will observe that there are nations to whom a great portion of the year is darkness, who are condemned to pass weeks and months without the benign influence of the solar rays. The central solar ray is now perpendicular to the tropic of Capricorn; the length of the days is inversely what it was when the sun entered

Cancer, the days being now at their shortest, and the nights longest in the northern hemisphere: the length of each is pointed out by the horary index.

The earth being again carried on till it enters Libra, and the sun Aries, we shall again have all the phenomena of the equinoctial seasons. The terminator will divide all the parallels into two equal parts; the poles will again be in the plane of the terminator; and consequently as the globe revolves, every place from pole to pole will describe an equal arc in the enlightened and obscure hemispheres, entering into and going out of each exactly at six o'clock, as shewn by the hour index.

As the earth advances, more of the northern polar circle comes into the illuminated hemisphere, and consequently the days increase with us, while those on the other side of the equator decrease, till the earth arrives at the first point of Capricorn, the place from which we first began to make our observations.

To explain the phenomena that take place in what is called a parallel, direct, and right sphere.

Take off the globe and its terminator, and put on in its place the globe which accompanies the instrument, and which is furnished with a meridian, horizon, and quadrant of altitude; the edge of the horizon is graduated from the east and west, to the north and south points, and within these divisions are the points of the compass to the under side of this horizon; but at 18 degrees from it another circle is affixed, to represent the twilight circle: the meridian is graduated like the meridian of a globe; the quadrant of altitude is divided into degrees, beginning at the zenith, and finishing at the horizon.

This globe, if the horizon be differently set with respect to the solar ray, will exhibit the various phenomena arising from the situation of the horizon with respect to the sun, either in a right or parallel, or an oblique sphere; or having set the horizon to any place, you will see by the central solar ray how long the sun is above or below the horizon of that place, and at what point of the compass he rises, his meridian altitude, and many other curious particulars, of which we shall give a few examples.

Set the horizon to coincide with the equator, and place the earth in the first point of Libra; then will the globe be in the position of a parallel sphere, and of the inhabitants of the poles at that season of the year, which inhabitants are represented by a pin at the upper part of the quadrant of altitude; the handle being turned round gently, the earth will revolve upon its axis, and the solar ray will coincide with the horizon, without deviating in the least to the north or south; shewing, that on the 21st of March the sun does not appear to rise or set to the terrestrial poles, but passes round through all the points of the compass, the plane of the horizon bisecting the sun's disk.

Now place the horizon so, that it may coincide with the poles, and the pin representing an inhabitant to be over the equator, the globe in this position is said to be in that of a right sphere; the equator, and all the parallels of latitude, are at right angles, or perpendicular to the horizon; by turning the handle till the earth has completed a year, or one revolution about the sun, we shall perceive all the solar phenomena as they happen to an inhabitant of the equator, which are, 1. That the sun rises at six, and sets at six, throughout the year, so that the days and nights there are perpetually equal. 2. That on the 21st of March, and 22d of September, the sun is in the zenith, or exactly over the heads of the inhabitants. 3. That one half of the year between March and September, the sun is every day full north, and the other half, between September and March, is full south of the equator, his meridian altitude being never less than 66½ degrees.

If the pin, representing an inhabitant, be now removed out of the equator, and set upon any place between it and the poles, the horizon will not then pass through either of the poles, nor coincide with the equator, but cut it obliquely, one half being above, the other half below the horizon; the globe in this state is said to be in that of an oblique sphere, of which there are as many varieties as there are places between the equator and both poles. But one example will be sufficient; for whatever appearance happens to one place, the same, as to kind, happens to every other place, differing only in degree, as the latitudes differ. Bring the pin, therefore, over London, then will the horizon represent the horizon of London, and in one revolution of the earth round the sun, we shall have all the solar appearances through the four seasons clearly exhibited, as they really are in nature; that is, the earth standing at the first degree of Libra, and the sun then entering into Aries, the meridian turned to the solar ray, and the hour index set to XII, you will then have the globe standing in the same position towards the sun, as our earth does at noon on the 21st of March. If the handle be turned round, when the solar ray comes to the western edge of the horizon, the hour index will point to VI, which shews the time of sun-setting; London then passes into, and continues in darkness, till the hour index having passed over XII hours, comes again to VI, at which time the solar ray gains the eastern edge of the horizon, thereby defining the time of sun-rising; six hours afterwards the meridian again comes to the solar ray, and the hour index points to XII; thereby evidently demonstrating the equality of the day and night, when the sun is in the equinoctial. You may then also observe, that the sun rises due east, and sets due west.

Continuing to move the handle, you will find, that the solar ray declines from the equator towards the north, and every day at noon rises higher upon the graduations of the meridian than it did before, continually approaching to London, the days at the same time growing longer and longer, and the sun rising and setting more and more towards the north, till the 21st of June, when the earth gets into the first degree of Capricorn, and the sun appears in the tropic of Cancer, rising about 40 minutes past 3 in the morning, and setting about 20 minutes past 8 in the evening, and after continuing about seven hours in the nether hemisphere, appears rising in the north-east, as before. From the 21st of June to the 22d of September, the sun recedes to the south, and the days gradually decrease to the autumnal equinox, when they again become equal.

During the three succeeding months, the sun continues to decline towards the south pole, till the 21st of December, when the sun enters the tropic of Capricorn, rising on the south-east point of the compass about 20 minutes past 8 in the morning, and setting about 40 minutes past 3 in the evening, at the south-west point upon the horizon; after which, the sun continues in the dark hemisphere for 17 hours, and then appears again in the south-east, as before. From this chill solstice the sun returns towards the north, and the days continually increase in length till the vernal equinox, when all things are restored in the same order as at the beginning.

Thus all the varieties of the seasons, the time of sun rising and setting, and at what point of the compass; as also the meridian altitude and declination every day of the year, and duration of twilight, and to what place the sun is at any time vertical, are fully exemplified by this globe and its apparatus.

Before we quit the phenomena particularly arising from the motion and position of the earth, let the globe, with the meridian and horizon, be removed, and the ivory ball, which fits upon a pin, be placed thereon, to represent the earth.

As the axis of this globe stands perpendicular to the plane of the ecliptic, you will find, that the solar ray continually points to the equator of this little ball, and will never deviate to the north or south; though, by turning the handle, the ball is made to complete a revolution round the sun. This shews, that the earth in this position would have the days and nights equal in every part of the globe, all the year long; there would have been no difference in the climates of the earth, no distinction of seasons; an eternal summer, or never-ceasing winter, would have been our portion; an unvaried sameness that would have limited inquiry, and satiated curiosity; and that the variety of the seasons is owing to its axis being inclined to the plane of its orbit.

OF THE LUNARIUM, *plate* 12, *fig*. 2.

Having thus illustrated the phenomena, which arise particularly from the inclination of the earth's axis to the plane of the ecliptic, from its rotation round its axis, and revolution round the sun; we now proceed to explain, by this instrument, the phenomena of the moon. But in order to this, it will be necessary to speak first of the instrument, which is put in motion like the preceding one, by the teeth on the fixed wheel; it is also to be placed upon the same socket as the tellurian, and confined down by the same milled nut, D, *fig.* 1.

The sloping ring, P Q, represents the plane of the moon's orbit, or path round the earth; so that the moon, in her revolution round the earth, does not move parallel to the plane of the ecliptic, but on this inclined plane; the two points of this plane, that are connected by the brass wires, are the nodes, one of which is marked ☊, for the ascending node, the other ☋, for the descending node. The moon is therefore sometimes on the north, and sometimes on the south side of the ecliptic, which deviations from the ecliptic are called her north or south latitude; her greatest deviation, which is when she is at her highest and lowest points, called her limits, is 5 degrees, 18 minutes; this, with all the other intermediate degrees of latitude, are engraved on this ring, beginning at the nodes, and numbered both ways from them. At each of the nodes, and at about 18 degrees distant from them, we find this mark ☉, and at about 22 degrees this ☽, to indicate, that when the full moon is got as far from the nodes as the mark ☽, there can be no eclipse of the moon; nor any eclipse of the sun, when the new moon has passed the mark ☉; these points are generally termed the limits of eclipses. The nodes of the moon do not remain fixed at the same point of the ecliptic, but have a motion contrary to the order of the signs.

T V is a small circle parallel to the ecliptic; it is divided into 12 signs, and each sign into 30 degrees; this circle is moveable in its socket, and is to be set by the hand, so that the same sign may be opposite to the sun that is marked by the annual index. These signs always keep parallel to themselves, as they go round the sun, but the inclined plane with its nodes go backwards, so that each node recedes through all the above signs in about 19 years. R S is a circle, on which are divided the days of the moon's age; X Y is an ellipsis, to represent the moon's elliptical orbit, the direct motion of the apogee, or the line of the apsides, with the situation of the elliptical orbit of the moon, and place of the apogee in the ecliptic at all times.

To rectify the lunarium.

Set the annual index, E, on the large ecliptic to the first of Capricorn; then turn the plate, with the moon's signs upon it, until the beginning of Capricorn points directly to the sun; turn the handle till the annual index comes to the first of January; then find the place of the north node in an ephemeris, to which place among the moon's signs, set the north node of her inclined orbit, by turning it till it is in its proper place in the circle of signs; set the moon to the day of her age.

GENERAL PHENOMENA OF THE MOON.

Having rectified the lunarium for use, on putting it into motion, it will be evident,

1. That the moon, by the mechanism of the instrument, always moves in an orbit inclined to that of the ecliptic, and consequently in an orbit analogous to that in which the moon moves in the heavens.
2. That she moves from west to east.
3. That the white, or illuminated face of the moon, is always turned towards the sun.
4. That the nodes have a revolution contrary to the order of the signs, that is from Aries to Pisces; that this revolution is performed in about nineteen years, as in nature.

5. That the moon's rotation upon her axis is effected and completed in about 27½ days; whereas it is 29½ days from one conjunction with the sun to the next.

6. That every part of the moon is turned to the sun, in the space of her monthly or periodic revolution.

To be more particular. On turning the handle, you will observe another motion of the earth, which has not yet been spoken of, namely, its monthly motion about the common center of gravity between the earth and moon, which center of gravity is represented by the pin Z. From hence we learn, that it is not the center of the earth which describes what is called the annual orbit, but the center of gravity between the earth and moon, and that the earth has an irregular, vertical, or spiral motion about this center, so that it is every month at one time nearer to, at another time further from the sun. It is evident, from this instrument, that the moon does not regard the center of the earth, but the center of gravity, as the center of her proper motion; that the center of the earth is furthest from the sun at new moon, and nearest at the full moon; that in the quadratures the monthly parallax of the earth is so sensible, as to require a particular equation in astronomical tables. These particulars were first applied to the orrery by the late ingenious Mr. *Benjamin Martin.*

To explain the phases of the moon.

The moon assumes different phases to us, 1. On account of her globular figure. 2. On account of the motion in her orbit, between the earth and the sun: for whenever the moon is between the earth and the sun, we call it new moon, the enlightened part being then turned from us; but when the earth is between the sun and the moon, we then call it full moon, the whole of the enlightened part being then turned towards us.

The phases of the moon are clearly exhibited in this instrument; for we here see that half which is opposite to the sun is always dark, while that which is next to the sun is white, to represent the illuminated part. Thus, when it is new moon, you will see the whole white part next the sun, and the dark part turned towards the earth, shewing thereby its disappearance, or the time of its conjunction and change: on turning the handle, a small portion of the white part will begin to be seen from the earth, which portion will increase towards the end of the 7th day, when you will perceive, that half of the light, and half of the dark side, is turned towards the earth, thus illustrating the appearance of the moon at the first quarter. From hence the light side will continually shew itself more and more in a gibbous form, till at the end of fourteen days the whole white side will be turned towards the earth, and the dark side from it, the earth now standing in a line between the sun and moon; and thus the instrument explains the opposition, or full moon. On turning the handle again, some of the shaded part will begin to turn towards the earth, and the white side to turn away from it, decreasing in a gibbous form till the last quarter, when the moon will appear again as a crescent, which she preserves till she has attained another conjunction.

In this lunarium the moon has always the same face or side to the earth, as is evident from the spots delineated on the surface of the ivory ball revolving about its axis in the course of one revolution round the earth; in consequence of which, the light and dark parts of the moon appear permanent to us, and the phases are shewn as they appear in the heavens.

As the earth turns round its axis once in 24 hours, it must in that time exhibit every part of its surface to the inhabitants of the moon, and therefore its luminous and opake parts will be seen by them in constant rotation. As the half of the earth which is opposed to the sun is always dark, the earth will exhibit the same phases to the lunarians that we do to them, only in a contrary order, that when the moon is new to us, we shall be full to them, and *vice versa.* But as one hemisphere only of the moon is ever turned towards us, it is only those that are in this hemisphere who can see us; our earth will appear to them always in one place, or fixed in the same part of the heavens; the lunarians in the opposite hemisphere never see our earth, nor do we ever view that part of the moon which they inhabit. The moon's apparent diurnal motion in the heavens is produced by the daily revolution of our earth.

If we consider the moon with respect to the sun, the instrument shews plainly, that one half of her globe is always enlightened by the sun; that every part of the lunar ball is turned to the sun, in the space of her monthly or periodical revolution; and that, therefore, the length of the day and night in the moon is always the same, and equal to 14¾ of our days. When the sun sets to the lunarians in that hemisphere next the earth, the terrestrial moon rises to them, and they can therefore never have any dark night; while those in the other hemisphere can have no light by night, but what the stars afford.

OF THE PERIODICAL AND SYNODICAL MONTH.

The difference between the periodical month, in which the moon exactly describes the ecliptic, and the synodical, or time between any two new moons, is here rendered very evident. To shew this difference, observe at any new moon her place in the ecliptic, then turn the handle, and when the moon has got to the same point in the ecliptic, you will see that the dial shews 27⅓ days, and the moon has finished her periodic revolution. But the earth at the same time having advanced in its annual path about 27 degrees of the ecliptic, the moon will not have got round in a direct line with the sun, but will require 28 days and 4 hours more, to bring it into conjunction with the sun again.

OF ECLIPSES OF THE SUN AND MOON.

There is nothing in astronomy more worthy of our contemplation, nor any thing more sublime in natural knowledge, than rightly to comprehend those sudden obscurations of the heavenly bodies, that are termed eclipses, and the accuracy with which they are now foretold. " One of the chief advantages derived by the present generation from the improvement and diffusion of philosophy, is delivery from unnecessary terror, and exemption from false alarms. The unusual appearances, whether regular or accidental, which once spread consternation over ages of ignorance, are now the recreations of inquisitive security. The sun is no more lamented when it is eclipsed, than when it sets; and meteors play their coruscations without prognostic or prediction."

We have already observed, that the sun is the only real luminary in the solar system, and that none of the other planets emit any light but what they have received from the sun; that the hemisphere, which is turned towards the sun, is illuminated by his rays, while the other side is involved in darkness, and projects a shadow, which arises from the luminous body.

When the shadow of the earth falls upon the moon, it causes an eclipse of the moon; when the shadow of the moon falls upon the earth, it causes an eclipse of the sun.

An eclipse of the moon, therefore, never happens but when the earth's opake body interposes between the sun and the moon, that is, at the full moon; and an eclipse of the sun never happens but when the moon comes in a line between the earth and the sun, that is, at the new moon.

From what we have already seen by the instrument it appears, that the moon is once every month in conjunction, and once in opposition; from hence it would appear, that there ought to be two eclipses, one of the sun, the other of the moon, every month; but this is not the case, and that for two reasons, first, because the orbit of the moon is inclined in an angle of about five degrees to the plane of the ecliptic; and secondly, because the nodes of this orbit have a progressive motion, which causes them to change their place every lunation. Hence it often happens, that at the time of opposition or conjunction the moon has so much latitude, or what is the same thing, is so much below or above the plane of the ecliptic, that the light of the sun will in the first case reach the moon without any obstacle, and in the other the earth; but as the nodes are not fixed, but run successively through all the signs of the ecliptic, the moon is often, both at the times of conjunction and opposition, in or very near the plane of the ecliptic; in these cases an eclipse happens, either of the sun or moon, according to her situation. The whole of this is rendered clear by the lunarium, where the wire projecting from the earth, shews when the moon is above, below, or even with the earth, at the times of conjunction and opposition, and thus when there will be, or not, any eclipses.

The distance of the moon from the earth varies sensibly with respect to the sun; it does not move in a circular, but in an elliptic orbit round us, the earth being at one of the foci of this curve. The longer axis of the lunar orbit is not always directed to the same point of the heavens, but has a movement of its own, which is not to be confounded with that of the nodes; for the motion of the last is contrary to the order of signs, but that of the line of apsides is in the same direction, and returns to the same point of the heavens in about nine years. This motion is illustrated in the lunarium by means of the brass ellipsis XY, *fig.* 2, which is carried round the earth in little less than nine years; thus shewing the situation of the elliptical orbit of the moon, and the place of the apogee in the ecliptic.

OF A NEW TERRESTRIAL GLOBE,* *plate* 13, *fig.* 2,

And of a new Apparatus adapted thereto, for solving, in an easy and natural manner, the several Phenomena of the Sun, Moon, and Earth.

Though globes have ever been considered as the best instruments of conveying general ideas of astronomy and geography, yet they have always been mounted in a way that must perplex and confuse the learner, and furnish him with ideas that are altogether false, and contrary to the nature of things.

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* The terrestrial globe was first improved by my father, and placed in a fixed position, &c. The floating meridian and horizon were added by Mr. *Newman.*

That you may clearly perceive the great advantages of a globe mounted like that before you, I shall first point out a few of the imperfections of globes mounted in the *common way*.*

Now, in the first place, what is rectifying a globe thus mounted, but a continual absurdity? For to rectify the globe to any particular latitude, the axis of the earth is continually shifted from one false position to another, the mind of the pupil is confused, and he with difficulty conceives, that the axis of the earth never varies its position, but always preserves the same inclination to the plane of its orbit.

The broad paper circle of the common globes is designed to represent the ecliptic and the horizon; but on examination you will find, it represents neither the one nor the other. Now the ecliptic is the apparent path of the sun, to which the earth's axis always makes an angle of 66½ degrees; now by shifting the axis of the globe, to rectify for the latitude, this circle can never be in its position as ecliptic, except when the axis is at 66½ degrees, and, consequently, cannot be used as the ecliptic. Now, let us consider it as the horizon. Now, every place is always in the zenith of the horizon, and the place and horizon always move together; but in the common globes, the broad paper circle is the only horizon in one situation, that is, when the place is in the zenith; after having rectified the globe to the latitude, the moment you move the globe, the broad paper circle is no longer the horizon. Thus it is plain, that this circle cannot with propriety be considered either as an horizon or ecliptic. As if it were to multiply confusion, a circle is laid down on the terrestrial globe to represent the ecliptic, and used as such in solving problems upon the common globes, though it involves the pupil in numerous absurdities: thus, having marked the sun's place in the ecliptic, and rectified the globe to the latitude, then turn the globe, and the sun and earth have a diurnal motion together; of course, if you have day when you begin, you will have the same during the whole twenty-four hours. Many other errors might easily be pointed out, but these are sufficient to shew you that no one can be properly taught by globes so mounted.

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* As I do not agree entirely with our Author, in what he considers the imperfections of globes mounted in the common manner; in my Appendix to this Lecture I have added a few explanatory observations thereon. EDIT.

The globe before you, *plate* 13, *fig*. 2, does not hang in a frame like the common globes, but is mounted on a pedestal, and is supported by, and moveable on, an axis, which is inclined 66½ degrees to the ecliptic, and of course is always parallel to the axis of the earth, supposing the path of the globe to be parallel to the ecliptic.* On the pedestal, but under the globe, is a graduated circle C D, marked with the signs and degrees of the ecliptic; adjoining thereto is a circle of months and days, answering to every degree of the ecliptic; within this circle is the sun's declination for every day of the month.

There is a moveable arm AB, which, being set to the day of the month, immediately points out the sun's place in the ecliptic, and his declination. On this moveable arm, but near the index, you observe a pillar E; on the top of the pillar is fixed a small ball, through which a steel wire passes, to represent a ray proceeding from the center of the sun.

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* Globes of 9 or 12 inches in diameter, when mounted in the above manner, are of the most convenient dimensions. If much accuracy is wanted, and no limited expense given, an 18 inch globe, so mounted, makes a very useful and illustrative instrument.

EDIT.

Round the globe is a brass circle F, to represent the horizon of any place; and at right angles to this horizon, is fixed a semicircle G, to answer for a general meridian. The middle point of this semicircle answers for the situation of any inhabitant on the earth, for which reason a steel pin is fixed over the middle point of this semicircle.

One supposition only is necessary for performing every problem with this globe; namely, that a spherical luminous body will enlighten one half a spherical opake body, and, consequently, that a circle at right angles to the central solar ray, and dividing the globe in half, will be a terminator, shewing the boundaries of light and darkness for any given day.

For this purpose, at the end of the moveable arm opposite to the sun, there is a pillar H, from the top of which projects a piece to carry a circle I, that surrounds the globe, and always divides it into equal portions, separating the enlightened from the dark parts. Eighteen degrees behind this circle, but parallel thereto, is another circle, to represent the limits of twilight.

There are two brass plates, K and L, under the globe, which are turned by the diurnal revolution thereof; each of them is divided into twice twelve hours and parts of an hour, to answer for the hours of day; on the outside are laid down the degrees of longitude for every hour; so that these circles give you at sight the hour of the day or night, at any two places on the globe, and the difference of longitude corresponding thereto.

There is one thing more relative to the globe, which renders it a planetary globe; for, by setting this pillar, *plate* 13, *fig.* 4, to the place of any planet in the ecliptic, and the ball to the latitude of the planet, it will solve all problems relative to that planet, or the moon; as it does for the sun, by means of a central solar ray.

To rectify this globe, set the division under the representative inhabitant over the given place, set the solar index, L, to the day of the month; then turn the globe round on the axis till the meridian coincides with the central solar ray, and the hour index under the globe to XII; and this globe is then in the position of our globe, with respect to the sun and that place, &c.

Place the inhabitant on the western side of the terminator, and he will see the sun or the central solar ray rising in the horizon, and this ray will mark thereon the sun's amplitude, and the hour circle gives you the hour and minute of the sun's rising on that day and place; turn the globe gradually till the meridian coincides with the central solar ray, and the point will mark out the sun's meridian altitude for that day. As the globe goes on, the altitude decreases, and when the inhabitant is arrived at the other side of the terminator, the solar ray is in the horizon, and points out the sun's amplitude, and you have the time of his setting on the hour circle. If you proceed to turn the globe till the inhabitant is under that circle which is behind the terminator, the hour circle gives the time that twilight finishes. The sun's altitude for any given time of the day, is obtained by stopping the globe when the index points out that hour, and the quadrant of altitude over the inhabitant, and then bringing it to the central ray, which will point out thereon the altitude for that hour.

In this manner you may solve the same questions for any other place, or any other day, always observing, 1. To fix the inhabitant over the given place. 2. To set the sun's annual index to the given day of the month. 3. To bring the meridian to the central solar ray, and the hour index under the globe to XII.

By placing the small pillar to the moon's place in the ecliptic, and the ball to her latitude, the same problems may be solved at the same time for the moon; and so respectively of any other planet.

By this globe, a person entirely unacquainted with astronomy may, in a few hours, acquire a competent and natural notion of the principal phenomena, and be enabled to solve the greatest part of the most interesting problems concerning the sun, moon, and planets.

OF THE CELESTIAL GLOBE, *fig.* 3, *plate* 13.

As the terrestrial globe is mounted to correspond exactly with the globe of our earth, and every problem answered as they are really occasioned by the annual and diurnal motion of the earth; so the celestial globe, to be conformable to nature, should be as nearly as possible an exact imitation of the heavens, and their situation with respect to the earth; which is far from being the case with the common globes.

To make the celestial globe thus conformable to nature, it should have no motion; the appearances of motion in the firmament arise from the diurnal motion of the earth; it is plain, therefore, that whatsoever gives a true representation of the heavens will have no motion. The celestial globe before you, is therefore fixed on an axis, making, like that of the terrestrial globe, 66½ degrees with the plane of the ecliptic; and the ecliptic on this globe exactly coincides with the sun's apparent path round the earth. All problems concerning the sun, moon, and planets, are performed by the terrestrial globe. This globe needs only be used for the stars, and one or two problems will give you a sufficient idea of the manner of solving all that relates to the stars.

To find the latitude and longitude of a given star. Find the star on the globe, and then place the index and clip, A, on the ecliptic plate, slide the siderial index till it is exactly over the star, and the latitude is shewn on the arc, and the longitude, b, the index, on the ecliptic.

To find the rising, setting, amplitude, and meridian altitude of the same star. Take the clip from the celestial globe, and put it to the same degree of longitude on the terrestrial ecliptic plate; turn the globe on its axis, and the time of its rising and setting is immediately pointed out by the hour index; its amplitude is shewn on the horizon; its meridian altitude, by the meridian; and its azimuth and altitude for any hour, by applying the quadrant of altitude under the siderial index for that hour.

I shall conclude my Lectures on these instruments with some observations that naturally arise from considering the art and ingenuity with which they are constructed. For, when we see materials working with an art and contrivance that is not in their nature, we are at once convinced that a superior intelligence has been concerned in their arrangement, &c.

Thus also in nature, whatever bears the marks of a wisdom not belonging to the known causes producing it, may be properly stiled *providential:* for, when agents void of wisdom act wisely, it is plain there must be some hand to conduct them, though we may not be able to perceive by what springs or channels of communication it operates. There wants, therefore, no long train of reasoning to lead us into the knowledge of a Providence. Penetration and closeness of thought have no further use in this case, than to discover the fallacy of those sophisms, wherein infidel writers endeavour to overcloud the most apparent truths. The plain man needs no assistance here from the philosopher, but may say to him as *Diogenes* did to *Alexander*, "Only please to stand out of my sun-shine."

Intelligence * is manifested two ways, either by means supplied to answer the end we conceive to have been had in view, though we do not discern the method by which they were prepared; or else by the contrivance apparent in productions, though we do not see what end they answer: the former more particularly gives us the display of providence; the latter, of the wisdom wherewith it is administered.

If you saw a house stored with furniture, utensils, and victuals; the gardens planted with herbs and fruit trees; the grounds stocked with cows, horses, deer, and poultry, all in a manner fitted for the entertainment and convenience of a family; you would certainly conclude, there was some master who had taken care to provide for the uses whereto they were respectively proper. Or, if an ignorant person went into a room where, among scales, weights, compasses, rules, and other things of common use, he should find quadrants, theodolites, armillary spheres, planetariums, tellurians, &c. of whose use, as well as of the figures upon them, he was entirely ignorant; yet he would know, without being told, that they were the works of some artificer proceeding with skill and contrivance, and who made them for purposes worthy the care with which they were finished.

In this manner we constantly reason upon common occasions, and there wants only a proper attention to lead us into the like train of thinking upon the phenomena of visible nature. For there you may perceive ample provision made in vast variety for the numerous family of *Adam*; corn, fruit, herbs, cattle, and fowl, for our sustenance; wool, flax, and cotton, for our cloathing; drugs and simples for our relief; air for our breathing; timber, stone, lime, and brick-earth for our habitation; wood and coal for our firing; beasts of burden for our assistance;

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* *Tucker*'s Light of Nature, vol. iii. part 1, p. 192.

winds to purify our atmosphere, to refresh our heats, and waft us from shore to shore; variety of climes and soils to bear us a produce of every kind; dews and rains to make them yield us their increase. The sea, that original source of water, so necessary to us for many uses, serves likewise to associate distant nations by opening the communication of commerce. The sun diffuses his warmth and light to cherish us. The distant stars guide us over the boundless ocean and the inhospitable desert, extend the fields of science to an immensity of space, and turn the rugged brow of night into a cheerful scene of contemplation.

Even within the narrow compass of our own bodies, we carry about no inconsiderable stores, without which we could not receive benefit from those around us. We have engines of digestion and secretion, springs and channels of circulation, limbs for instruments of action, bones for our support and protection, organs of speech for our mutual intercourse. What a multitude of vessels, glands, and ducts, to concoct and distribute our aliment! What artificial structure and excellent disposition of muscles and joints, to serve for instruments of action! What amazing nicety in the organs of sense! The eye, with her humours and coats mathematically arranged, and duly proportioned one among the other; the ear in winding modulating the vibrations of air into sounds; the nerves in imperceptible threads running every where through the fleshy parts, yet returning their notices without impediment from the furthest extremities of our limbs! And all this complicated machine, containing an infinitude of multiform works, is bound up in a small compass, yet with such stupendous skill, that they do not interfere with each others operations, nor fall into discord upon our motions!

We have appetite to stimulate, senses to inform, the faculties of comparing, distinguishing, judging, to enlighten, and reason to direct us. In the capacity of our senses and affections, we have sources of pleasure, enjoyment, and innocent mirth.

In the multitude of the objects of creation, we find a provision made and suited to our various organs, tastes, and faculties, a fund for bodily support, subjects for intellectual inquiries and mental gratification. " Which shall we admire most, the multitude of our organs, their finished form and faultless order, or the power which the mind exercises over them? Ten thousand veins are put into her hands, and yet she manages and conducts them all without the least perplexity or irregularity; with a promptitude, a consistency, that nothing else can equal; touching every spring of the human machine with the most masterly skill, though she knows nothing of the nature of her instrument, or the process of her operation.

If you turn your eyes upon the vegetable tribes, you perceive them, in countless multitudes of trees, shrubs, weeds, mosses, &c. each growing, spreading, and flourishing, by laws adapted to its own kind; and all worked with such exactness and nicety of art, as the greatest human ingenuity could not imitate; their sap vessels curiously woven within the stem, and dispersed among the roots and branches; their leaves wrought finer than needle-work. The finest works of the loom and the needle, when examined with a microscope, appear so rude and coarse, that a savage might be ashamed to wear them: but, when the work of God is brought to the same test, we see how fibres, too minute for the naked eye, are composed of others still more minute; and these again of others; till the primordial threads, or first principle of the texture, are utterly undiscernable; while the whole substance presents a celestial radiance in its colouring, as if it were intended for the cloathing of an angel.

Yet are these wonders of the vegetable world surpassed by those of the animal, whose frame contains a more complicated machinery, capable of more admirable play: for, besides the engines of growth and nutriment analogous in both, the animal is furnished with organs of sensation, and instruments of activity. What a richness of invention is displayed in the variety of their forms, and the diversity of their cloathing. Nor can we help remarking those surprising instincts that severally guide them to their harbours, their foods, their ways of breeding and preservation, instruct them to build their nest, to make their comb, to spin their webs, and provide for the future without knowledge of their wants.

Nor must we omit the uses and qualities assigned to animals, that we can turn commodiously to our advantage: we have not to seek our wool from the fierce lion, nor want the untameable tyger to plow our grounds; but the ox, the horse, and the sheep, have docility and manageableness given them for their characteristics. Creatures saleable in the market are more prolific than those of the savage kind. Poultry and rabbits keep within their accustomed purlicus; but nobody knows where to find the coarse-grained heron, or the worthless cuckoo.*

" O Lord, how manifold are thy works; in wisdom hast thou made them all; the earth is full of thy riches! All creatures wait upon thee, that thou mayest give them their meat in due season. When thou givest it them they gather it, and when thou openest thine hand they are filled with good." How great and beautiful is this idea! The hand of man scatters food to the few creatures that are about him; but when the hand of God is opened, a world is fed and satisfied.†

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* Rev. *W. Jones's* Sermons, vol. ii. p. 63. † Ibid. p. 104.

APPENDIX TO LECTURE XLIII.

BY THE EDITOR.

CONTAINING A PARTICULAR DESCRIPTION OF THE BEST SIMPLE PORTABLE ORRERY; COMPARATIVE OBSERVATIONS ON THE DIFFERENT MODES OF MOUNTING GLOBES; AND A DESCRIPTION OF THE PORTABLE EQUATORIAL INSTRUMENT. *Plate* 14, *fig.* 2.

As our Author has not given a full reference to the several parts of the orrery, as noticed in page 156, and its being of the kind the most portable and complete hitherto made, I have thought it better to add here a further description of the machine, and some observations on globes and the equatorial.

The words, *orrery* and *planetarium*, are frequently used indifferently to signify the same instrument. Among instrument makers, the term, orrery, is generally given to a large and complete machine, shewing all the motions of the planetary bodies in the most perfect manner possible by wheel-work. The term, planetarium, is given to an instrument shewing chiefly the periodical revolutions of the primary planets; the word, *tellurian*, to an instrument shewing completely the annual and diurnal motions of the earth only; and *lunarium*, to an instrument shewing the motions and various appearances of the moon only.

These instruments have been made of various degrees of magnitude and perfection, and the completest sort are those that exhibit by wheel-work the periodical revolutions of the satellites, as well as the primary planets and their diurnal motions. The quantity of wheel-work, as well as other machinery, to produce such motions, creates an expense unavoidably great. *Rowley's* grand orrery, as made of late years by *Wright*, appears to be the most expensive one ever made in this country; the expense of which, I am informed, did not exceed 500l. It will be unnecessary to enter here into a detail of the very considerable varieties of inferior orreries since made by *Ferguson*, *Martin*, and myself; we now make them from 100 guineas downwards to one guinea, and therefore suitable to the purposes and purses of all students and amateurs of astronomy.

The orrery now selected by our Author, see *plate* 11, *fig.* 1, and *plate* 12, *fig.* 1 and 2, was contrived by the late learned and ingenious instrument maker Mr. *B. Martin*, about the year 1770, and in a small pamphlet published by him in 1771, was announced as an orrery of a new construction, representing in the various parts of its machinery all the motions and phenomena of the planetary system.

For a portable instrument, it is in my opinion the most complete and elegant ever made; excepting the ivory balls representing the planets, it is all made of brass. The brass box, A B C, *plate* 11, *fig.* 1, is about 11 inches in diameter, and instead of being supported upon three short feet, as represented in the plate, we make the box to be supported on a brass pillar and claw feet, like the stand of the tellurian, *plate* 13, *fig.* 3, as originally done by the inventor: in this manner, it is found to be more commodious and conspicuous when in use. To represent all the various motions of the planets by wheel-work in one machine, occasions it to be of great bulk and weight; Mr. *Martin*, by constructing his machine into parts, certainly diminished that unity and magnificence of one great and elegant machine, but at the same time decreased very considerably the expense, and rendered the apparatus, notwithstanding, very simple, complete, and instructive.

The component parts of this orrery are as follow:

1. A *planetarium*, *plate* 11, *fig*. 1, exhibiting the order, motion, and aspects, of all the primary planets of our system. The new Georgian planet is not represented in the figure, but is usually applied by us to the instrument. The planets are easily put on or taken off from their respective sockets occasionally. Their heliocentric places in the ecliptic below, for the day, are to be first set by the assistance of *White*'s Ephemeris or the Nautical Ephemeris for the year; then, by turning the winch or handle they will all move from west to east, with the same respective motions and periodical times as they have in the heavens; thus representing in a just manner the Pythagorean, and Copernican or Solar System.

For the representation of the Ptolemaic, or vulgar system, our Author has already given directions at page 168, et seq.

The apparatus, *plate* 11, *fig*. 2 and 3, is used to exemplify the apparent retrograde motions and direct positions, sometimes, of the planets. You take off the ivory earth ⊕, and place the socket, P, upon the wire in its stead; the socket, *fig*. 3, is to be applied upon either the arms of Mercury ☿, or Venus ♀, instead of the ivory balls. The retrograde arm or wire, *fig*. 2, about the part F, is then to be placed on the nut piece, as shewn at *fig*. 3; this wire represents a ray of light coming from the planet to the object; and the small ball, the planet as it appears among the stars in the heavens. When the winch is turned, the direct motion, stationary position, and apparent retrograde motion of the inferior planets, as seen from the earth, will be clearly shewn agreeable to what our Author has before related, see page 165, and *plate* 11, *fig*. 2.

2. The *tellurian*, *plate* 12, *fig.* 1, is the second part of this orrery. When the planetary arms are all taken off from their central sockets, this part is to be applied; it is made fast on the socket by the brass screw nut, D. The globe is three inches in diameter, by which is accurately and evidently shewn all the phenomena arising from the annual and diurnal motions of the earth. For this purpose, the axis of the earth keeps a perfect parallelism and constant inclination to the plane of the ecliptic: the circle of illumination or terminator, H, divides the globe into its enlightened and dark hemispheres, and by the dial plate, N O, under the globe, it will appear at what hour the sun rises and sets to every country and on every day of the year. There is an index, G, to shew when it is noon or the sun is upon the meridian of any particular place; by the same index is also shewn what sign or degree of the ecliptic the sun is in for every day, the parallel of declination it describes, and the length of the diurnal and nocturnal parts of that parallel in the light and dark hemispheres. At times it is convenient to have a slower motion of the earth, for which there is in the box a provision made, and you have only to shift the winch from one hole in the side of the box to the other.

When the tellurian is used, it is to be put upon the socket of the earth, and placed exactly over the degree of the ecliptic which the earth possesses that day, or so that the index, E, at the end of the arm may point to the sun's place in the ecliptic; and then screwing it fast upon the socket by the nut D, and turning the winch, the proper motions will commence.

To explain more completely the various phenomena of the earth, another three inch globe is made furnished with a brass divider, meridian, horizon, and quadrant of altitude, similar to those shewn at *plate* 13, *fig.* 2, all graduated; and also a circle to represent the twilights. By this, all the chief problems on the terrestrial globe may be performed and illustrated in a very natural manner, and has been described by our Author at page 175.

3. The *lunarium*, *plate* 12, *fig.* 2, is placed upon the same socket, *fig.* 1, instead of the tellurian. Its machinery is also put into motion by the teeth of the large fixed ecliptic plate P Q. The motions shewn by this part answer all the phenomena of a satellite or moon revolving about its primary, while that moves about the sun. These motions and appearances are as follow:

1. The menstrual motion of the earth and moon about the common center of gravity, at z, *fig.* 2, between them.

2. The circular motion of this center of gravity about the sun, which describes the true annual orbit, and in which the earth has a very irregular, or rather vermicular motion, from one side to the other, being in each month nearer to and farther from the sun.

3. The monthly motions of the moon, *viz.* the periodical month, in which the moon describes exactly the ecliptic; and the synodical month, which shews the space or time between two moons or conjunctions.

4. The annual parallel motion of the ecliptic shewing the place of the moon; by the ring, T Q, the place of the nodes; by the oval ring, X V, the apogee and perigee, as also the geocentric motions, places, and aspects of the sun and all the planets.

5. The retrograde motion of the nodes, with the inclination of the lunar orbit, and the degree of her latitude from the ecliptic in every part.

6. The direct motion of the apogee, or the line of the apsides, with the situation of the elliptic orbit of the moon, and the place of the apogee in the ecliptic at any time.

7. The mechanism of the wheels, &c. being such as to shew the phases of the moon, and always to shew the same face to the earth, every way similar to the face of the moon in the heavens at the same time.

By such a variety of motions in the lunarium, it will be easy to see the rationale of most of the lunar irregularities and variable phenomena; also every thing relative to the nature and doctrine of eclipses, both solar and lunar, total, annular, and partial.

A small brass lamp to be lighted with oil and cotton, or a wax taper, usually accompanies the instrument, which is fitted to the stem where the sun is applied. In a darkened room with the lamp lighted, the several phenomena, exhibited by the parts of the machine, are more illustrative and striking.

A machine, or secondary planetarium, is sometimes made, either to correspond with that of *plate* 11, *fig.* 1, or to be occasionally connected with it, and is called the *Jovian system.* This part shews the motions of Jupiter's four moons or satellites, as nearly corresponding to their motions in the heavens as the latest observations upon them will admit of. The distances of the satellites have here the same proportions as in the heavens, which are expressed in semidiameters and decimal parts of Jupiter's globe. In a similar way, machines are made to represent the motions of the satellites of Saturn, and of the Georgian planet.

To illustrate the nature and manner of the precessions of the equinoxes, and the phenomena of the transits of Mercury and Venus over the face of the sun, apparatuses might easily be adapted; but, like the Jovian and Saturnian machines, they are only made from particular orders, as not being the most material parts of the orrery.

COMPARATIVE OBSERVATIONS ON GLOBES, MOUNTED IN THE COMMON MANNER, AND THOSE MOUNTED IN THE IMPROVED METHOD, *see plate* 13, *fig.* 2 and 3.

As I do not agree in opinion with our late Author in his assertion, that the mounting of globes in the common way, renders them unfit for the intended purposes of instruction, and as conveying unnatural and confused ideas to the learner, see page 188, I will only trouble the reader with a few remarks, and leave him to judge which he conceives to be the most perspicuous and useful for his purpose; both methods, in many cases, have their advantages.

Globes are not designed as instruments of accurate calculation, or universal illustration; they are made for the assistance, in a familiar way, of beginners, in the performance of a variety of useful and instructive problems in the sciences of astronomy, geography, navigation, spherical trigonometry, dialling, chronology, &c. &c. The more simple the manner of mounting globes for these purposes, the more easy and familiar will the operations be found by the learner. On this account, I always preferred the method of a well-divided horary circle at the north pole, to the semicircular wires and sliding points, adopted originally by our late Author's father. In the new 18 inch globes, noticed in my note in page 572, vol. iii. I have constructed the hour circles with such clear and fine divisions, as to shew the time to five minutes of a degree, which is quite sufficient for all the material problems, and is as accurate as the fitting up of a globe to be depended upon, can be made.

No terrestrial globes convey just representations of the position of our earth and the heavens, for any particular day, till they are rectified completely, and duly set by the compass. In respect to the shifting of the inclination of the axis or the north pole, considered by our Author as an absurdity, it must be observed, that when properly set, the horizon is a true representation of the place it is rectified for. The relative position of the horizon to the axis are the same in both methods of mounting.

In the globe mounted, as shewn in *plate* 13, *fig*. 2, the moveable horizon is shifted, as it would naturally shift, should an inhabitant move from one latitude to another. In the common globe you elevate the pole to the same effect; and, though in London, should you elevate the pole for the latitude of Jamaica, the axis at London would not point to the north pole, or polar star; yet, supposing you were at Jamaica, it would then point justly. The axis of the earth, with respect to the horizon, may therefore be said, relatively to the horizon, to be continually shifting, as an inhabitant changes his latitude. This can be easily understood by the learner, and not be the means of any confused ideas.

The horizon on the broad paper circle upon the stand of the globes, containing the ecliptic, divided into signs and degrees, and a contiguous calendar, is not designed to represent more than the horizon of a place. The graduated circle of the ecliptic is useful for finding the place of the sun for any day in a ready manner, without the trouble of referring to an ephemeris; the sun's place being found, the ecliptic circle upon globe is immediately used to have the requisite mark set on it. The sun's place being thus fixed on the globe, the performance of a problem, by turning the sun and globe round together, is certainly not strictly agreeable to nature, but in part so, and is quite sufficient for the result of the problem.

In the inspecting of particular countries on the terrestrial globe, it is proper to have it quite clear, and without being obliged to push away any contiguous appendages. For the performance of the problems on the planets, and tracing the paths of comets, &c. the celestial globe, mounted in the common way, will be found more convenient. Upon the whole, therefore, I judge the following particulars to be the chief advantages in the improved mounted globes, and those in the common manner.

Advantages peculiar to the new mounted globes, as represented in plate 13, fig. 2 and 3.

1. The axis always retains a natural and permanent position, directing to the north pole in the heavens, when duly set by the compass.

2. The sun upon the stem E, *fig.* 2, moon, or planets, being in a fixed position, and the globe turning about its axis before, is the natural and just representation of the cause of all the various phenomena respecting their rising, culminating, setting, lengths of days and nights, &c. resulting from the diurnal motion of the earth, and the respective situations of the planets in their orbits.

3. The moveable horizon, meridian, &c. applied to the globe, are to have their positions naturally changed, according to the motion or situation of an inhabitant of the globe.

4. The globe being placed in a darkened room, and a candle or lamp being placed at a proper distance, in a line with the center of the sun; the globe will be divided, as in nature, into the enlightened and darkened hemisphere, and shew in what degree the various countries enjoy the presence of the sun or day, and the lengths at that time of the year of the day and night.

3. By the wheel-work, contained underneath the plate C D, the relative position of the axis to the terminator of light and darkness is shewn, consequently, the state of the light and darkness of the globe at any season of the year. This change of the position of the axis is not agreeable to nature, but sufficient to explain the phenomena. In this instance it makes a complete tellurian upon a large scale; but, in respect to the permanent parallelism of the axis, it will be best explained by the tellurian of the improved orrery before described, see *plate* 12, *fig.* 1.

Advantages peculiar to the globes, mounted in the common manner.

1. Their having no brass circles or other appendages, contiguous to their surfaces, renders them easy and accurate for inspection, and in the performance of a variety of problems.

2. The external appendages are less in quantity than in the globle shewn at *plate* 13, *fig.* 2, consequently more easy and ready to the learner.

3. In many cases, where the use of a quadrant of altitude is necessary, they are done in a ready manner, that could not be in that of the new mounted one.

4. All great circles of the sphere, being imaginary, and referred to in the heavens, the position of right, parallel, and oblique, to the inhabitants of the globe, can only be represented by the common mounted globe, where there is a contrivance of the horary circle being under the meridian, or to shift away occasionally from the pole.

5. Globes of large dimensions, such as 18 inches in diameter and upwards, are much less expensive and portable, mounted in the common way, than in the other way.

These observations are quite sufficient to give the reader a general idea of the merits, and unavoidable defects of both mountings. In the performance of a variety of problems upon the common globe, he will find many others that are not necessary to be noticed here; and to convince him, that a rational knowledge of the celestial phenomena can only be obtained by joining observations of the heavenly bodies with the portions of his studies on globes, orreries, and other astronomical instruments.

Besides the methods of mounting globes just described, other mountings are applied for the purposes, as follow,

1. A globe to shew the phenomena of the transits of Mercury and Venus over the sun.

2. A globe to shew the phenomena of solar and lunar eclipses on all places of the terrestrial globe, called an *eclipsareon.*

3. A globe to shew the nature and manner of the precession of the equinoxes, and thereby the difference between the sidereal and tropic years, as also the apparent and direct motion of the fixed stars.

4. A celestial globe, with a telescope to fix on the north pole of the globe occasionally, with a divided arc, &c. &c. An apparatus of my invention for observing any celestial body, and thereby, in an instantaneous manner, obtaining all the particulars of any phenomena presenting themselves in the heavens.

5. A lunar globe, or the *selenegraphia,* invented by Mr. *John Russel,* R.A. forming an apparatus for exhibiting the phenomena of the moon, and the useful purposes to which it may be applied.

A DESCRIPTION OF THE EQUATORIAL, OR UNIVERSAL SUN-DIAL.

In the former edition of this Work, our Author omitted the description of the equatorial, as represented in *plate* 14, *fig*. 2. A description, with a variety of problems to be performed with it, he published in his *Astronomical and Geographical Essays*, 8vo. 4th edit. 1794, and to which I must refer the reader, as the limits of this work will admit but of a concise description and use of the instrument.

An equatorial instrument is the most general and comprehensive of all instruments made for the purposes of practical astronomy. It is the best of any to exercise the beginner in the science. For when he has obtained a perfect knowledge of the management of this, there will be no other construction of an astronomical machine, but what he will comprehend the use of in a ready manner.

An equatorial is considered by astronomers as an instrument useful in taking the following particulars of the heavenly bodies: their altitudes and azimuths, their right ascensions and declinations, to determine the latitudes and longitudes of places, to find by observations on the sun and stars the hour of the day and night, to measure angles universally, or the distances of objects on land, and to take angles in general for the resolution of many problems in practical astronomy, trigonometry, &c. &c.

Plate 14, *fig*. 2, represents one of the smallest dimensions usually made. Its equatorial circle, M N, is about four inches in diameter, and the rest in proportion. The instrument consists of the following parts: an horizontal circle E F, divided into four quadrants of 90° each, with a fixed nonius or vernier scale at N, and the circle itself may be turned by the hand on its center or axis. A strong pillar is fixed to the center of the horizontal circle, supporting the center of a vertical semicircle AB, divided into two quadrants of 90° each. This is called the semicircle of altitude, as it is used to take angles of altitude and depression. There is a vernier scale at K.

At right angles to the plane of this semicircle, the equatorial circle, MN, is fixed, representing the equator of the globe, and divided into 24 hours, or twice 12 hours, each hour being subdivided into five minutes. Upon this circle moves another with a chamfered edge, carrying a nonius, by which the divisions of the equatorial are further subdivided, and are read off to single minutes. At right angles to this circle is fixed the semicircle of the declination, D, divided into two quadrants of 90° each.

The brass bar, that carries the sight OP, is fixed to an index moveable on the semicircle, and carrying a nonius at Q. The sight O, to which the eye is to be applied, has two small holes, and a dark glass for screening the eye from the sun; and the sight, P, has two small pieces screwed on, the lower with a small hole to admit the rays from the sun, and the upper two cross wires for observations by their intersection. There are two spirit levels, L, L, fixed on the horizontal circle, at right angles to each other, which, with the three adjusting screws, I, G, H, are useful for duly levelling the instrument.

A small telescope is sometimes applied in room of the two sight pieces P, O.

I shall here insert our Author's directions for adjusting the instrument, and one problem, as an example of its use; for further information the reader may consult his *Astronomical Essays*.

PROBLEM I. *To adjust the equatorial for observation.*

Set the instrument on a firm support. First, to adjust the levels, and the horizontal or azimuth circle. Turn the horizontal circle till the center line, or o, of the divisions coincides with the middle stroke of the nonius, or near it. In this situation, one of the levels will be found to lie either in a right line joining the two foot-screws, which are nearest the nonius, or else parallel to such a right line. By means of the two last-mentioned screws, cause the bubble in the level to become stationary in the middle of the glass; then turn the horizontal circle half round, by bringing the other o to the nonius; and if the bubble remains in the middle, as before, the level is well adjusted; if it does not, correct the position of the level, by turning one or both of the screws which pass through its ends, by means of a turn-screw, till the bubble has moved half the distance it ought to come to reach the middle; and cause it to move the other half, by turning the foot-screws already mentioned. Return the horizontal circle to it first position, and if the adjustments have been well made, the bubble will remain in the middle; if otherwise, the process of altering the level and the foot-screws, with the reversing, must be repeated till it bears this proof of its accuracy. Then turn the horizontal circle till 90° stands opposite to the nonius; and by the foot-screw immediately opposite the other 90°, without touching the others, cause the bubble of the same level to stand in the middle of the glass. Lastly, by its own proper screws set the other level, not yet attended to, so that its bubble may occupy the middle of its glass.

Secondly, to adjust the line of sight. Set the nonius on the declination semicircle at o, the nonius on the horary circle at VI, and the nonius on the semicircle of altitude at 90°. Look through the sights towards some part of the horizon, where there is a diversity of remote objects. Level the horizontal circle, and then observe what object appears on the center of the cross wires. Reverse the semicircle of altitude, so that the other 90° may apply to the nonius; taking care, at the same time, that the other three nonii continue at the same parts of their respective graduations as before. If the remote object continues to be seen on the center of the cross wires, the line of sight is truly adjusted; but if not, unscrew the two screws which carry the frame of the cross wires, and move the frame till the intersection appears to lie on a new object, half way between the object first observed, and that to which the wires are applied in the last position. Return the semicircle of altitude to its original position: if the intersection of the wires be then found to be on the object to which they were last directed, the line of sight is truly adjusted; but if not, the frame must be again altered as before: and the same general operation must be repeated, till the cross wires in both positions apply to the same object.

Besides this adjustment of the center of intersection, it is necessary that one of the wires should be in the plane of the declination semicircle, and the other at right angles to that plane. As the wires are fixed at right angles to each other, the adjustment of one of them will be sufficient. For this purpose, observe any small object on one of the wires; if it be the vertical wire, move the index of the semicircle of declination; or if the other, move the last-mentioned semicircle on the axis of the equatorial circle. In either case, the object will coincide with the wire during its motion, if the position be right; if not, alter that position, taking care not to displace the center from its adjustment.

To adjust the piece which carries the hole for forming the solar spot, direct the sights to the sun, so that the center of the luminous circle, formed by the aperture which carries the cross wires, may fall precisely on the upper sight-hole. Then move the frame, with the small perforation, till the solar spot falls exactly on the lower sight-hole.

Thirdly, to find the correction to be applied to observations by the semicircle of altitude. Set the nonius on the declination semicircle to o, and the nonius on the horary circle to XII; direct the sights to any fixed and distant object, by moving the horizontal circle and semicircle of altitude, and nothing else; note the degree and minute of altitude or depression; reverse the declination semicircle, by directing the nonius on the horary circle to the opposite XII; direct the sights again to the same object by means of the horizontal circle and semicircle of altitude, as before. If its altitude, or depression be the same as was observed in the other position, no correction will be required; but if otherwise, half the difference of the two angles is the correction to be added to all observations or rectifications made with that quadrant, or half of the semicircle, which shews the least angle; or to be subtracted from all observations or rectifications made with the other quadrant, or half.

When the levels and cross wires are once truly set, they will preserve their adjustment a long time if not deranged by violence; and the correction to be applied to the semicircle of altitude is a constant quantity.

For observations on the sun and the rest of the heavenly bodies, a suitable fixed position in a room should be determined for the instrument.

PROBLEM II. *To measure angles, either of azimuth, altitude, or depression.*

Set the middle mark of the nonius on the declination at o, and fix it by means of the milled screw behind. Set the horary circle at XII, on the equator, and the instrument, previously adjusted, is ready for observation. Then, if the sights be directed successively to any two objects, the degrees and minutes contained between the two positions of the nonius, on the limb of the horizontal circle, will shew the horizontal angle of the quadrant. And likewise, if the sights be directed to any object, by moving the horizontal circle and semicircle of altitude, the degree and minute marked by the nonius on the last-mentioned semicircle will be the angle of altitude, if on the quadrant or part nearest the eye; or of depression, if on the remoter quadrant.

Remark. It is proper in this place to describe the nature and use of the admirable contrivance, commonly called a *vernier* or *nonius.* It depends on the simple circumstance, that if any line be divided into equal parts, the length of each part will be greater, the fewer the divisions; and, contrariwise, it will be less in proportion as those divisions are more numerous. Thus it may be observed, that the distance between the two extreme strokes on the nonius, in the equatorial before us, is exactly equal to eleven degrees on the limb, but that it is divided into twelve equal parts. Each of these last parts will therefore be shorter than the degree in the proportion of 11 to 12; that is to say, it will be one-twelfth part, or five minutes shorter. Consequently, if the middle stroke be set precisely opposite to any degree, the relative positions of the nonius and the limb must be altered five minutes of a degree, before either of the two adjacent strokes next the middle, on the nonius, can be brought to coincide with the nearest stroke of a degree; and so, likewise, the second strokes on the nonius will require a change of ten minutes; the third of fifteen, and so on to thirty, when the middle line of the nonius will be seen to be equidistant between two of the strokes on the limb; after which, the lines on the opposite side of the nonius will coincide in succession with the strokes on the limb.

It is clear from this, that whenever the middle stroke of the nonius does not stand precisely opposite to any degree, the odd minutes, or distance between it and the degree immediately preceding, may be known by the number of the stroke on the nonius, which coincides with any of the strokes on the limb. It must be observed, however, that as the degrees in the several quadrants are reckoned in opposite directions, so likewise the nonius has two sets of numbers: for the use of which, it need only be remembered, that they always begin from the middle, and go to 30 minutes, and thence from the opposite 30 minutes in the same direction to the middle; and that they must always be reckoned in the opposite direction to the degrees on the limb.

In this instrument they must be read in the opposite direction; but when the nonius plate has its divisions fewer than the number of parts on the limb to which it is equal, they coincide successively in the same direction as that of the motion of the index.

The angles by this small equatorial are customarily shewn to 5′ of a degree, and the time to 1 minute.

Equatorials, when made for accuracy, are of much larger dimensions, and the various circles moved by teeth and pinion. The equatorial circle is commonly made from 6 to 18 inches diameter, and the angles shewn to 1 minute of a degree, and the time to 10 seconds.

It is an instrument not now so much in repute as formerly. The several circles are very difficult to be made without some small eccentricity.* The better kind are therefore now made upon a simpler construction: or, instead of them, a vertical and horizontal circle, called a *circular instrument*, which, having but two principal centers or axes, is found more accurate and permanent. The altitude and azimuth of the objects are only by this obtained; but these are the chief data in practical astronomy and topography, and from which all the requisite deductions and purposes can readily be obtained.

The usual diameters of the principal vertical circle of the circular instrument are from 12 inches to 2 feet, but there are no fixed dimensions; the construction of the observatory, or place of observation, is the chief guide to the astronomer in the choice of his instruments.

To these instruments, as well as to the equatorial of the better kind, achromatic telescopes are applied, that will enable the observer to see the planets and stars in the day time.

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* It is now the practice in all the best and large angular instruments to apply two opposite verniers or nonii, by which any small eccentricity is easily observed and allowed for after the observation.

LECTURE XLIV.

OF THE FIXED STARS.

No part of the universe gives such enlarged ideas of the structure and magnificence of the heavens, as the consideration of the number, magnitude, and distance of the fixed stars.

We admire, indeed with propriety, the vast bulk of our own globe; but when we consider how much it is surpassed by most of the heavenly bodies, what a point it degenerates into, and how little more even the vast orbit in which it revolves would appear, when seen from some of the fixed stars, we begin to conceive more just ideas of the extent of the universe, and the boundaries of creation.

The most conspicuous and brightest of the fixed stars of our horizon is Sirius. The earth, in moving round the sun, is 190 millions of miles nearer to this star in one part of its orbit, than in the opposite; yet the magnitude of the star does not appear to be in the least altered, or its distance affected by it: so that the distance of the fixed stars is great beyond all computation. The unbounded space appears filled at proper distances with these stars, each of which is probably a sun, with attendant planets rolling round it. In this view, what, and how amazing, is the structure of the universe!

Though the fixed stars are the only marks by which astronomers are enabled to judge of the course of the moveable ones, and we have asserted their relative positions do not vary; yet this assertion must be confined within some limits, for many of them are found to undergo particular changes, and perhaps the whole are liable to some peculiar motion, which connects them with the universal system of created nature. Dr. *Herschel* even goes so far as to suppose, that there is not, in strictness of speaking, one fixed star in the heavens; but that there is a general motion of all the starry systems, and consequently of the solar one among the rest.

There are some stars, whose situation and place were heretofore known, and marked with precision, that are no longer to be seen; new ones have also been discovered, that were unknown to the ancients, while numbers seem gradually to vanish. There are others, which are found to have a periodical increase and decrease of magnitude; and it is probable, that the instances of these changes would have been more numerous, if the ancients had possessed the same accurate means of examining the heavens, as are used at present.

New stars offer to the mind a phenomenon more surprizing, and less explicable, than almost any other in the science of astronomy; I shall select a few instances of the more remarkable ones for your instruction: a consideration of the changes that take place, at so immense a distance as the stars are known to be from you, may elevate your mind to consider the immensity of HIS power, who regulates and governs all these wide extended motions; "who hath measured the waters in the hollow of his hand, and meted out heaven with a span."

Who turns his eye on Nature's midnight face,
But must inquire—What hand behind the scene,
What arm almighty, put these wheeling globes
In motion, and wound up the vast machine?

It was a new star discovered by *Hipparchus*, the chief of the ancient astronomers, that induced him to compose a catalogue of the fixed stars, that future observers might learn from his labours, whether any of the known stars disappeared, or new ones were produced. The same motives engaged the illustrious *Tycho Brahe* to form, with unremitting labour and assiduity, another new catalogue of the stars.

Of new stars, the first of which we have a good account, is that which was discovered in the constellation of Cassiopea, in the month of November of the year 1572, a time when astronomy was sufficiently cultivated, to enable the astronomers to give the account with precision. It remained visible about sixteen months; during this time, it kept its place in the heavens without the least variation. It had all the radiance of the fixed stars, and twinkled like them; and was in all respects like Sirius, excepting that it surpassed it in brightness and magnitude. It appeared larger than Jupiter, who was at that time in his perigee; and was scarce less bright than Venus.

It was not by degrees that it acquired this diameter, but shone forth at once in its full size and brightness, as if of instantaneous creation. It continued about three weeks in full and entire splendor, during which time it might be seen even at noon day, by those who had good eyes, and knew where to look for it. Before it had been seen a month, it became visibly smaller, and from thence continued diminishing in magnitude till March, 1574, when it entirely disappeared. As it decreased in size, it varied in colour; at first, its light was white, and extremely bright; it then became yellowish, afterwards of a ruddy colour, like Mars; and finished with a pale livid white, resembling that of Saturn.

In 1596, *Fabricius* observed a new star in the neck of the Whale: he first saw it in August, and it disappeared in October of the same year. In 1637, *Phocyllides Holwarda* observed it again, and not knowing that it had been seen before, took it for a new discovery: he watched its place in the heavens, and saw it appear again the succeeding year, nine months after its disappearance. It has been since found to be every year very regular in its period, except that in 1672 it was missed by *Hevelius*, and not seen again till 1676. *Bullialdus* having compared together the observations which had been made of it from 1638 to 1666, determined the periodical time between this star's appearing in its greatest brightness, and returning to it again, to be 333 days; observing further, that this star did not appear at once in its full magnitude, or brightness, but by degrees arrived at them. He also framed an hypothesis, to account for these periodic changes.

Three changeable or re-apparent stars have been discovered in the constellation of the Swan; the first was seen by *Jansonius*, in 1600; the second was discovered in 1670; the third by *Kirchius*, in 1686.

In the latter end of September, 1604, a new star was discovered near the heel of the right foot of Serpentarius. There were in that part of the heavens, at that time, the three superior planets, which so engaged the attention of astronomers, that no appearance thereabouts could have long escaped them. *Kepler*, in describing it, says, that it was precisely round, without any kind of hair, or tail; that it was exactly like one of the stars, except that in the vividness of its lustre, and the quickness of its sparkling, it exceeded any thing he had ever seen before. It was every moment changing into some of the colours of the rainbow, as yellow, orange, purple, and red; though it was generally white, when it was at some distance from the vapours of the horizon. Those in general who saw it, agreed, that it was larger than any other fixed star, or even any of the planets, except Venus: it preserved its lustre and size for about three weeks; from this time it grew gradually smaller. *Kepler* supposes, that it disappeared some time between October, 1605, and the February following, but on what day is uncertain.

Besides these several re-apparent stars, so well characterized and established by the earliest among the modern astronomers, there have been many discovered since, by *Cassini*, *Maraldi*, and others; Mr. *Montanere* speaks of having observed above one hundred changes among the fixed stars.

PROPER MOTION OF THE STARS.

Many stars have been found to alter their position with respect to those to which they were adjacent, and this change of position has been termed the *proper motion of the stars.*

The proper motion of Sirius, Castor, Procyon, Pollux, Regulus, Arcturus, and Aquilæ, in 100 years in right ascension, are respectively, 1 minute, 3 seconds; 1 minute, 28 seconds; 1 minute, 33 seconds; 41 seconds; 2 minutes, 20 seconds; and 57 seconds. The proper motion of Sirius in declination, in a century, is 2 minutes; and of Arcturus is 3 minutes, 21 seconds; both tending to the south.

The apparent brightness of some of the fixed stars is observed to be periodic. The star Algol, in Medusa's head, has been observed long since to appear of different magnitudes, at different times. The period of it has been lately settled by *J. Goodrick*, Esq. of York. It periodically changes from the first to the fourth magnitude; the time employed from one greatest diminution to the other, was, in the year 1783, at a mean, 2 days, 20 hours, 49 minutes, 3 seconds. The changes are thus: during four hours it gradually diminishes in lustre; during the succeeding four hours, it recovers its first magnitude by a like gradual increase; and during the remaining part of the period, namely, 2 days, 12 hours, 49 minutes, 3 seconds, it invariably preserves its greatest lustre; after the expiration of which term, the diminution again commences.

The causes of these appearances cannot be assigned at present, with any degree of probability; perhaps they have some analogy to the spots on the sun, which at some times appear in greater numbers than at others, some of them bigger than the whole earth; or perhaps they are owing to some real motions of the stars themselves.

There are several stars that appear single to the naked eye, which are, on examination with a telescope, found to consist of two, three, &c. The number of double stars observed before the time of Dr. *Herschel*, was but small; but this celebrated astronomer has noted upwards of four hundred; among these, some that are double, others that are treble, double double, quadruple, double treble, and multiple; his catalogue gives the comparative size of these stars, their colour as they appeared to him, with several other very curious particulars.

HERSCHEL ON THE CONSTRUCTION OF THE UNIVERSE.

Before I leave the subject of the fixed stars, I shall endeavour to give you an account of Dr. *Herschel*'s ideas of the construction of the universe. Former astronomers had supposed that our sun, besides occupying the center of his own system, was also the center of the universe; and that the siderial heavens might be properly represented on the concave surface of a sphere: but these are ill adapted, says the Doctor, for a delineation of the interior parts of the heavens. Being able to penetrate into these regions by means of large telescopes,* we may now consider them as a naturalist regards a rich extent of ground, or a chain of mountains, containing strata variously inclined and directed, and composed of very different materials. He gives strong reasons, deduced from a series of observations, as well as considerations drawn from analogy, to prove that the visible system of nature, which we call the universe, consisting of all the celestial bodies, and many more than can be seen by the naked eye, is only a group of stars of suns, with their planets, constituting one of those patches called a nebula; and this is, perhaps, not one ten thousandth part of the universe.

Dr. *Herschel* found that his large telescope completely resolved the whitish appearance of the Via Lactea into stars. Having viewed and guaged this bright zone in all directions, he found it composed of shining stars, whose number constantly increases and diminishes, in proportion to its apparent brightness to the naked eye. There is no doubt, says he, but that the Milky Way is a most extensive stratum of stars of various sizes, and that our sun is one of the heavenly bodies belonging to it.

The portion of the Milky Way that he first observed, was that about the hand and club of Orion; here he found an astonishing multitude of stars, which he attempted to number, by estimating the number contained in the field of his telescope at once, and computing from a mean of these how many might be contained in a given portion of the Milky Way: in the most vacant places about that part, he found 63 stars; other six fields contained 110, 60, 70, 90, 70, and 74 stars; a mean of these gives 79 for the number of stars in each field; so that allowing 15 minutes for the diameter of his field of view, a belt of 15 degrees long, and 2 degrees broad, could not contain less than 50,000 stars, large enough to be distinctly numbered; besides which, he suspected twice as many more, which could be seen only now and then by faint glimpses, for want of sufficient light.

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* Dr. *Herschel's* observations, on which this theory is founded, were made with a Newtonian reflector, of 20 feet focal length, and an aperture of 18 inches.

It is very probable, that the great stratum, called the Milky Way, is that in which the sun is placed, though not in the very center of its thickness. This is gathered partly from the appearance of the Galaxy, which seems to encompass the whole heavens, as it certainly must do, if the sun is within the same. For, suppose a number of stars arranged between two parallel planes, infinitely extended every way, but at a given considerable distance from each other, and calling this a siderial stratum, an eye placed somewhere within it will see all the stars in the direction of the planes of the stratum projected into a great circle, which will appear lucid on account of the accumulation of the stars; while the rest of the heavens at the sides will only seem to be scattered over with constellations, more or less crowded, according to the distance of the planes, or number of the stars contained in the thickness or sides of the stratum.

If the eye were placed without the stratum, but at no very great distance, the appearance of the stars within it would assume the form of one of the lesser circles of the sphere; which would be more or less contracted, according to the distance of the eye: if this was exceedingly increased, the whole stratum might at last be drawn into a lucid spot of any shape, according to the position, length, and height of the stratum. What has been instanced in parallel planes, may be easily applied to strata irregularly bounded, and running in various directions; and thus any kind of curvatures, as well as various degrees of brightness, may be produced in the projection.

From appearances, he infers that the sun is placed in one of the great strata of the fixed stars, and very probably not far from the place where some smaller stratum branches out from it. Such a supposition accounts for all the phenomena of the Milky Way with great ease and simplicity, while every star in the stratum will have its own Galaxy, with only such variations in form and lustre, as may arise from their particular situation.

There is, says Dr. *Herschel*, a remarkable clearness and purity in the heavens, when we look out of our stratum at the sides, that is, towards Leo, Virgo, and Coma Berenices on one side, and towards Cetus on the other; whereas the ground of the heavens becomes troubled as we approach towards the length or height of it. These troubled appearances are easily to be explained, by ascribing them to some of the distant straggling stars, that hardly yield light enough to be distinguished; but when we look towards the pole of our system, where the visual ray does not graze along the side, the straggling stars of course will be very few in number, and therefore the ground of the heavens will appear much purer and more clear.

Dr. *Herschel* points out the methods whereby the sun's place in the siderial stratum may be ascertained, but these demand more previous knowledge than is necessary in an introductory lecture like the present. After this, he lays down some suppositions on the subject, taking a point of view at a very remote period of time, and an immense distance of space; these for the same reason we shall leave untouched, and proceed to his view of the heavens from our own retired station, in one of the planets, attending to a star in its great combination with numberless others; and in order to investigate what will be the appearances from this contracted situation, let us begin with the naked eye.

The stars of the first magnitude being in all probability the nearest, will furnish us with a step to begin the scale. Setting off, therefore, with the distance of Sirius or Arcturus, for instance, as unity, we shall at present suppose, that those of the second magnitude are at double, those of the third at treble the distance, &c. Taking it for granted then, that a star of the seventh magnitude, the smallest visible to the naked eye, is about seven times as far as one of the first, it follows, that an observer, who is inclosed in a globular cluster of stars, and not far from the center, will never be able by his naked eye to see to the end of it; for since, according to the foregoing estimations, he can only extend his view to about seven times the distance of Sirius, it cannot be expected that his eyes should reach the borders of a cluster, which has perhaps no less than 50 stars in depth every where around him. The whole universe therefore, to an observer confined to unassisted vision, will be comprized in a set of constellations richly ornamented with scattered stars of all sizes. Or, if the united brightness of a neighbouring cluster of stars should, in a remarkably clear night, reach his sight, it will put on the appearance of a small, faint, whitish nebulous cloud, not to be perceived without the greatest attention. Let us suppose him placed in a much extended stratum, or branching cluster of millions of stars: here the heavens will not only be richly scattered over with brilliant constellations, but a shining zone or milky way will be perceived to surround the whole sphere of the heavens, owing to the combined light of the stars that are too remote to be seen; our observer's sight will be so confined, that he will imagine this single collection of stars, though he does not perceive the thousandth part of them, to be the whole contents of the heavens. Allowing him now the use of a common telescope, he begins to suspect that all the milkiness of the bright path, which surrounds the sphere, may be owing to stars: he perceives a few clusters of them in various parts of the heavens, and finds also that there is a kind of nebulous patches; but still his views are not extended to reach so far as to the end of the stratum in which he is situated; so that he looks upon these patches as belonging to that system which to him seems to comprehend every celestial object. He now increases his power of vision, and applying himself to a closer observation, finds that the milky way is indeed no other than a collection of very small stars: he perceives that those objects, which had been called nebulæ, are evidently nothing but clusters of stars; their number increases upon him; and whilst he resolves one nebula into stars, he discovers ten new ones that he cannot resolve. He then forms the idea of immense strata of fixed stars, of clusters of stars, and of nebulæ, till going on with such interesting observations, he soon finds that all these appearances arise from the confined situation in which we are placed. Confined it may be justly called, though contained in no smaller a space than what appeared before to be the whole region of fixed stars, but which now has assumed the shape of a crookedly branching nebula; not one of the least, but probably very far from being the most considerable, of those numberless clusters that enter into the construction of the heavens. Dr. *Herschel* confirms these ideas by a series of observations, and thinks it will be found upon the whole, that this view, with all its consequential appearances, as seen by an eye inclosed in one of the nebulæ, is no other than a drawing from nature, wherein the features of the original have been closely copied; and Dr. *Herschel* hopes the resemblance will not be called a bad one, when it shall be considered how very limited must be the pencil of an inhabitant of so small and retired a spot of an infinite system, in attempting the picture of so unbounded an extent.

In the most crowded parts of the Milky Way, he has had a field of view of 588 stars, and these continued for many minutes; so that in one quarter of an hour's time, not less than 116,000 stars have passed through the field of his telescope: he endeavours to shew, that the powers of his telescope are such, that it will not only reach the stars at 497 times the distance of Sirius, so as to distinguish them, but that it also shews the united lustre of the accumulated stars that compose a milky nebulosity at a far greater distance. From these considerations, it is highly probable that, as his 20 feet telescope does not shew such a nebulosity in the Milky Way, it goes already far beyond its extent; and, therefore, a more powerful instrument would remove all doubt, by exposing a milky nebulosity beyond the stratum, which could then no longer be mistaken for the dark ground of the heavens.

To the foregoing arguments we may add the following, drawn from analogy. Dr. *Herschel* says, that among the great number of nebulæ which he has already seen, amounting to more than 900, there are many in all probability, equally extensive with that which we inhabit; and yet they are all separated from each other by very considerable intervals. Some indeed there are, that seem to be double and treble; and though with most of them it may be, that they are at a very great distance from each other, yet he does not mean to say that there are no such conjunctions; though there may be also some thinly scattered solitary stars, not yet drawn into systems; their number cannot be very considerable: a conjecture that is abundantly confirmed, in situations where the nebulæ are near enough to have their stars visible; for they are all insulated, and generally to be seen upon a very clear and pure ground, without any star near them that might be supposed to belong to them: and though they may be often seen in beds of stars, yet from the size of these stars, we may be certain that they are much nearer to us than those nebulæ, and belong undoubtedly to our own system.

THE ORIGIN OF NEBULOUS STRATA.

Dr. *Herschel* thinks the nebula that we inhabit, has fewer marks of profound antiquity upon it than the rest; having previously supposed that the condensation of clusters of stars is to be ascribed to a gradual approach; the number of ages that must have passed before some of the clusters could be so far condensed as they are at present, makes him naturally ascribe a certain air of youth and vigour to many very regularly scattered regions of our sidereal system. There are many places, where he asserts that there is reason to believe, that the stars, if we may judge from appearances, are now drawing towards various secondary centers, and will, in time, seperate into different clusters so as to occasion many sub-divisions. Our system, after numbers of ages, may be divided so, as to give rise to a stratum of two or three hundred nebulæ.

AN OPENING IN THE HEAVENS.

Some parts of our system seem to have already sustained greater ravages from time than others: in the body of the Scorpion there is an opening or hole, which is probably owing to this cause; it is four degrees broad.

A PERFORATED NEBULA, OR RING OF STARS.

Among the curiosities of the heavens, should be placed a nebula that has a regular concentric dark spot in the middle, and is probably a ring of stars; it is of an oval shape; in the northern side three very faint stars may be seen, as also one or two in the southern: the vertices of the longer axis seem less bright, and not so well defined as the rest.

PLANETARY NEBULÆ.

These are so named from a singularity of appearance, which renders it difficult to class them. Their light is so uniform and vivid, the diameters so small and well defined, as to make it improbable that they should be common nebulæ: if nebulæ, they must be compressed and condensed in the highest degree.

Though the words *condensation* and *cluster* often occur in the foregoing extract, we are by no means to infer that any of the celestial bodies, in our nebula, are nearer to one another than we are to Sirius, whose distance is supposed to be not less than 38 millions of miles. The whole extent of the nebula, being in some places near 500 times this distance, must be such, that the light of a star placed at its extreme boundary, supposing it to fly with the velocity of twelve millions of miles every minute, must have taken near 3000 years before it could reach us.*

These immense spaces, these numerous hosts of systematic universes, are probably connected the one with the other. Like so many immense circuses, by the mutual contact of their circumambient spheres, they press each other: these aerial atmospheres being also connected and interwoven together by an infinity of insertions, constitute a celestial sphere, which is again linked with others, till by an infinity of orbs they obtain a form, which is the origin and pattern of all forms, in which all the variegated sidereal revolutions harmoniously concur to one and the same end; that of mutually strengthening and establishing each other, and forming a celestial union.

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* The exact positions of new planetary nebulæ, &c. as discovered by Dr. *Herschel*, and communicated to me by him, are placed on the new 18 inch British celestial globe. Edit.

OF THE TELESCOPIC APPEARANCE OF THE PLANETS.

OF THE SUN.

"The observations which might with fulness of evidence confirm the opinion of planetary worlds, seem to be placed out of our reach, and we can scarce hope to make our optical instruments sufficiently perfect to render the inhabitants thereof visible to us. All, therefore, that we can do, is to examine if the planets are accommodated with those things which we are used to consider as necessary to animal existence. Lands, seas, clouds, vapours, and an atmosphere, or body of air, are objects that we may expect to find on the face of an inhabitable world."

By means of the telescope, we are enabled in some measure to ascend into the celestial region, and view the sun, moon, and stars, as they would appear to us if they were brought so many times nearer to us as the telescope magnifies; the light proceeding from the luminary we are looking at being diminished in the same proportion.

The telescope is one of those discoveries, of which no idea could have been formed, previous to the period in which the Supreme Being was pleased to unveil to the human mind some of the mysterious powers of glass: the importance of this discovery, and the extent to which it may be carried, still lie hid among the secrets of infinite wisdom. It is by this instrument more than by any other, that we have been led onward in our advances towards a perfect knowledge of the heavenly bodies, and that astronomy has been raised, from little more than a catalogue of stars, into a science.

When we look at the sun through a telescope even of moderate power, the eye being defended by a piece of coloured or smoked glass, nay, even by the naked eye, when guarded in the same manner, we discover on his surface many black, or rather less bright spots, of various sizes and shapes. Sometimes these spots will vanish in a very short time after their first appearance; sometimes they travel over his whole disk, or visible surface, from west to east, when they disappear, and in twelve or thirteen days they appear again, so as to be known, by their magnitude and figure, to be those that had disappeared before. Those, however, which are of the longest continuance, do not appear to have much solidity of consistence, for in a little time they also vanish, or become bright like the rest of the surface.

The spots are more frequent at some periods than at others; in some years, the sun's disk has for many months been perfectly free from them; in others, he has for months been more or less obscured by spots: the most remarkable phenomena of these spots, as observed by *Schenier* and *Hevelius*, are as follow: 1. Every spot, which has a nucleus, or dark part, hath also an umbra, or fainter shade, surrounding it. 2. The boundary betwixt the nucleus and umbra is always distinct and well defined. 3. The increase of a spot is gradual, the breadth of the nucleus and umbra dilating at the same time. 4. In like manner, the decrease of a spot is gradual, the breadth of the nucleus and umbra diminishing at the same time. 5. The exterior boundary of the umbra never consists of sharp angles, but is always curvilinear, how irregular soever the outside of the nucleus may be. 6. The nucleus of a spot, whilst on the decrease, often changes its figure, by the umbra incroaching irregularly upon it, insomuch, that in a small space of time new incroachments are discernable, whereby the boundary between the nucleus and umbra is perpetually varying. 7. It often happens, that by these incroachments the nucleus of a spot is divided into two or more nuclei. 8. The nuclei of the spots vanish before the umbra. 9. Small umbræ are often seen without nuclei. 10. A large umbra is seldom seen without a nucleus in the middle of it. 11. When a spot, which consisted of a nucleus and an umbra, is about to disappear, if it be not succeeded by a facula, or spot, brighter than the rest of the disk, the place it occupied is in a very little time not to be perceived.

In the Philos. Trans. vol. lxiv. the reader will find several curious observations on these spots by Professor *Wilson* and the Rev. Mr. *Wolaston*. The latter gentleman says, he once saw, with a twelve-inch reflector, a spot burst to pieces, while he was looking at the sun; the appearance was to him as that of a piece of ice, when dashed on a frozen pond, which breaks to pieces, and slides in various directions.

The spots are by no means confined to one part of the sun's disk, though we do not know that any have been observed about his polar regions. Though their direction is from east to west, yet the paths they describe in their course over the disk, are exceedingly different, sometimes being in straight lines, sometimes in curves; at one time descending from the northern to the southern part of the disk, at other times ascending from the southern to the northern part.

The larger spots, most of which exceed the whole earth in apparent magnitude, last a considerable time, sometimes three months before they disappear, at which time they are generally converted into spots exceeding the rest of the sun in brightness. The general opinion concerning their nature is, that they are volcanoes, or burning mountains of immense size; and that when the eruption is nearly ended, and the smoke dissipated, the fierce flames are exposed, and appear as luminous spots. *D. Wilson* supposes them, on the other hand, to be excavations in the luminous matter, or atmosphere, that environs the body of the sun.

The diameter of a spot near the middle of the disk, is measured by comparing the time it takes in passing over a cross hair in a telescope, with the time wherein the whole disk of the sun passes over the same hair. It may also be measured by a micrometer. *Hevelius* observed a spot that rose and vanished in 16 or 17 hours. None have been observed to continue longer than 70 days.*

Dr. *Herschel*'s opinion of the spots on the sun has been given in my note in page 17 of this volume. It may be proper to add here, from the changes in the atmosphere of Jupiter he accounts for the phenomena of his belts; and on a similar principle he illustrates the various appearances of a solar spot which he observed in the sun in 1779. This spot, he says, extended above 50,000 miles, and he thinks may be easily and satisfactorily explained, if we allow that the real body of the sun itself was seen on this occasion, though we rarely see more than its shining atmosphere. This hypothesis he also applies to the solution of phenomena exhibited by other spots, as observed by him. Edit.

OF THE MOON.

When we look at the moon with the naked eye, we discern a great number of irregular spots on her disk, distinguished by their dark colour from the brighter or more glaring parts; but when viewed through a telescope their number is prodigiously increased; and it is perceived, that many of these appearances are occasioned by vast obscure pits or cavities, and elevations or mountains. The spots in the moon always keep their places, not being moveable like those of the sun. Sometimes more or less of the northern, and southern, and eastern, and western part of the disk is seen, which is owing to what is called her libration.

These mountains and cavities are known to be such, from the shadow they cast. In the first and second quarters, when the light of the sun falls obliquely upon them, the elevated part casts a triangular shadow on the side opposite to the sun; whereas, with respect to the cavities, these have that side which is opposite to the sun illuminated, and that which is next the sun is dark and obscure, the same as would happen to a hollow bason, placed on a table at some distance from a candle, in a room where there is no other light. The shadows shorten as the sun becomes more directly opposed to the anterior face of the moon, and at length disappear at the time of the full. During the third and last quarters, the shadows appear again, but all fall towards the contrary side of the moon, though still with the same distinction, namely, that the mountains are dark and shady on the side farthest from the sun, and the pits are dark on the side next the sun.

The full moon is a very pleasing sight through a telescope, and has a great variety of lustre and colour; but it is not the face on which to discover the mountains, these are best seen at the increase or decrease; for, besides the evidence derived from the shadows, we may then see the tops of these mountains catching the rays of the sun before they reach that part of the surface on which their bottoms are placed.

On April 19, 1787, Dr. *Herschel* observed some appearances on the surface of the moon, which, judging by analogy from things perceived here with us, he thought he might term *volcanoes*. Three of these he observed in different places of the dark part of the moon; two of them appeared nearly extinct, or going to break out; the third, as an actual eruption of fire, or luminous matter. On the 20th it burnt with greater violence, and might be computed to be about three miles in diameter: the eruption resembled a piece of burning charcoal, covered by a thin coat of white ashes; all the adjacent parts of the volcanic mountain were faintly illuminated by the eruption, and were gradually more obscure as they lay at a greater distance from the crater. Dr. *Herschel* had, in 1783, observed an eruption, somewhat similar to that of the foregoing volcano. Indeed an appearance of this kind had been seen before, by *Don Ulloa*, in an eclipse of the sun. It was a small bright spot, near the margin of the moon, which he supposed to be a hole with the sun's light shining through it.

That the moon is surrounded by an atmosphere, is rendered probable by many observations of the solar eclipses, in which the edge or limb of the sun was observed to tremble just before the beginning. The planets are likewise observed to change their figure from round to oval, just before the beginning of an occultation behind the moon, which can be attributed to no other cause, than that their light is refracted by being seen through the moon's atmosphere. That we see no clouds, will not appear surprizing, if we consider, that the lunar days and nights are thirty times as long as ours; it will be easy to conceive, that with them the phenomena of vapours may be very different from what they are with us; perhaps their clouds and rain, if any, may be condensed into visible quantities only during the absence of the sun, and of course when they must be invisible to us.*

Mercury being at all times near the sun, we can only distinguish by the telescope a variation of his figure, which is sometimes that of a half moon, sometimes a little more or less than half.

Venus, when in the form of a crescent, and at her brightest times, affords a more pleasing telescopic view than any other of the heavenly bodies; her surface is diversified with spots, like those of the moon; by the motion of these, the time she takes up in revolving upon her axis is discovered. With a powerful telescope, mountains like those in the moon may be seen.†

Mars appears always round and full, except at the time of the quadrature, when its disk appears like that of the moon about three days after the full. By the spots which are seen on its surface, its diurnal revolution has been ascertained. From its characteristic ruddiness, and from other phenomena, it has been supposed, that its atmosphere is nearly of the same density with ours. Dr. *Herschel* has observed two white luminous circles surrounding the poles of this planet; they are supposed to arise from the snow lying about those parts.

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* Dr. *Herschel* conceives, that probably all the planets emit light in some degree from their circumambient atmospheres, consisting of various elastic fluids, some of which exhibit a shining brilliancy, while others are merely transparent; and that from the removal of this fluid the dark body of the planet becomes visible.

As a proof of this, he alledges the observation of a lunar eclipse in 1790, in which there could be no illumination from the rays reflected by our atmosphere, the focus in which they meet being more than 189,000 miles beyond the moon. Edit.

† Dr. *Herschel* has observed a faint illumination in the unenlightened part of the planet Venus, which he ascribes to some phosphoric quality of its atmosphere. Edit.

The appearance of Jupiter through a telescope, opens a vast field for speculative inquiry. The surface is not equally bright, but is distinguished by certain bands, or belts, of a duskier colour than the rest of the surface, running parallel to each other, and to the plane of its orbit. They are not regular or constant in their appearance; sometimes only one is seen, at other times eight have been seen; their breadth is likewise variable, one belt growing narrow while another in its neighbourhood becomes broader, as if one had flowed into the other; in this case an oblique belt has been observed to lie between them, as if for the purpose of forming a communication. Sometimes one or more spots are formed between the belts, which increase till the whole is united in one large dusky band. There are also bright spots to be discovered on Jupiter's surface; these are rather more permanent than the belts, and re-appear after unequal intervals of time. The remarkable spot, by whose motion the rotation of Jupiter on his axis was ascertained, disappeared in 1694, and was not seen again till 1708, when it re-appeared exactly in the same place, and has been occasionally seen ever since. The disappearance and re-appearing of the spots is not so wonderful as the changes that have been observed in the belts; the elder *Cassini* saw one evening five belts upon the planet, but while he was viewing them, they underwent the most surprizing change. In an hour from their fullest appearance there remained only three out of five, and one of these scarce perceptible. The most remarkable telescopic appearances of this planet, are the satellites, but these

I have particularly described under the head of *satellites.*

Though the great distance of the planet Saturn, and the tenuity of its light, do not permit us to distinguish the varieties of its surface; yet some of the first discoveries made by the telescope were on this planet, and the ring is still one of the most curious phenomena we are acquainted with. There is not, indeed, any thing in the whole system of nature more wonderful than this ring, which appears nearly as bright as any part of the surface of the planet: by what means it is suspended, or by what law supported; whether it is only a bright but permanent cloud, or whether it is a vast number of satellites disposed in the same plane, whose blended light gives it to us the form of one continual body, we can only form crude conjecture. M. *Messier* has observed on the anses of this ring several luminous white twinkling points, differing in vivacity from each other.

Sometimes our eye is in the plane of the ring, and then it becomes invisible: as its plane always keeps parallel to itself, it disappears twice in every revolution of the planet, that is, about once in fifteen year; and he sometimes appears quite round for nine months together. At other times the distance betwixt the body of the planet and the ring is very perceptible, insomuch that Dr. *Clarke*'s father saw a star through the opening. When Saturn appears round, if our eye be in the plane of the ring, it will appear as a dark line across the middle of the planet's disk; if the eye be elevated above the plane, a shadowy belt will be visible; when the plane appears, the ring next the body is the brightest; when the ring appears of an elliptical form, the parts about the ends of the largest axis are called ansæ. These, a little before and after the disappearing of the ring, are of unequal magnitude.

It has been supposed, that the ring has a rotation round an axis.

With very long telescopes two belts have been discovered on Saturn, which appear parallel to that formed by the edge of the ring; these are said to be permanent: *Cassini* and *Fatio* perceived a bright streak upon Saturn which was not permanent, being visible one day, disappearing the next, when another came into view near the edge of his disk. Besides these there are its five satellites, mentioned under their proper heads.

OF COMETS.

Comets are a kind of stars, appearing at unexpected times in the heavens, and of singular and various figures, descending from far distant parts of the system, with great rapidity, surprizing us with the singular appearance of a train, or tail; and, after a short stay, are carried off to distant regions, and disappear.

They were imagined in ancient times to be prodigies hung out by the immediate hand of God in the heavens, and intended to alarm the world. Their nature being now better understood, they are no longer terrible. But, as there are still many who think them to be heavenly warnings, portents of future events, it may not be improper to inform you, that the Architect of the universe has framed every part according to divine order, and subjected all things to laws and regulations; that he does not hurl at random stars and worlds, and disorder the system of the whole glorious frame, to produce false apprehensions of distant events, fears without foundation, and without use. Religion glories in the test of reason, of knowledge, and of true wisdom; it is every way connected with, and is always elucidated by them. From philosophy we may learn, that the more the works of the Lord are understood, the more he must be adored; and that his superintendency over every portion is more clearly evinced, and more fully expressed by their unvaried course, than by ten thousand deviations.

The existence of an universal connexion between all the parts of nature is now generally allowed. Comets undoubtedly form a part of this great chain; but of the part they occupy, and of the uses for which they exist, we are equally ignorant. It is a portion of science whose perfection is reserved for some distant day, when these bodies and their vast orbits may, by long and accurate observation, be added to the known parts of the solar system; when astronomy will appear as a new science, after all our discoveries, great as we at present imagine them to be.

The astronomy of comets is very imperfect; for but little can be known with certainty, where but little can be seen. Comets afford few observations on which to ground conjecture, and are for the greatest part of their course beyond the reach of human vision; but that they are not meteors in the air is plain, because they rise and set in the same manner as the moon and stars; they are called comets, from their having a long tail somewhat resembling the appearance of hair; some, however, have appeared without this appendage, as well defined and round as planets.

It is generally supposed, that they are planetary bodies, making part of our system, revolving round the sun in extremely long elliptic curves; that as the orbit of a comet is more or less eccentric, the distance to which they recede from the sun will be greater or less. Very great difference has been found by observation in this respect, even so great, that the sides of the elliptic orbit in some cases degenerate almost into right lines. They are very numerous: 450 are supposed to belong to our solar system.

Those comets, which go to the greatest distance from the sun, approach the nearest to him at their return.

Their motions in the heavens are not all direct, or according to the order of the signs, like those of the other planets. The number of those which move in a retrograde manner, is nearly equal to those whose motion is direct.

The orbits of most of them are inclined in very large angles to the plane of the ecliptic.

The velocity with which they move is variable in every part of their orbit; when they are near the sun, they move with incredible swiftness; when very remote from him, their motion is inconceivably slow.

When they appear, they come in a direct line towards the sun, as if they were going to fall into his body: and after having disappeared for some time, in consequence of his extreme brightness, they fly off on the other side as fast as they came, continually losing their splendor, till at last they totally disappear. Their apparent magnitude is very different, sometimes seeming not bigger than the fixed stars, at other times equal in diameter to Venus. *Hevelius* observed one in 1652, which was not inferior to the moon in size, though not so bright; its light pale and dim, its aspect dismal.

A greater number of comets are seen in the hemisphere towards the sun, than in the opposite; and are generally invisible at a smaller distance than that of Jupiter. Mr. *Brydone* observed one at Palmero, in July 1770, which, in 24 hours, described an arc in the heavens upwards of 50 degrees in length; so that if it was far distant from the sun, it must have moved at the rate of upwards of 60 millions of miles in a day.

They differ also in form from the other planets, consisting of a large internal body, which shines with the reflected light of the sun, and is encompassed with a very large atmosphere, apparently of a finer matter, much resembling that of the Aurora Borealis; this is called the head of the comet, and the internal part the nucleus. When a comet arrives at a certain distance from the sun, an exhalation arises from it, which is called the tail.

The tail is always directed to that part of the heavens which is directly or nearly opposite to the sun, and is greater and brighter, after the comet has passed its perihelion, than in its approach to it; being greatest of all when it has just passed the perihelion. The tail of the comet of 1680 was of a prodigious size, extending from the head to a distance scarcely inferior to that of the sun from the earth.

No satisfactory knowledge has been acquired concerning the cause of that train of light which accompanies the comets. Some philosophers imagine, that it is the rarer atmosphere of the comet impelled by the sun's rays. Others, that it is the atmosphere of the comet, rising in the solar atmosphere by its specific levity; while others imagine, that it is a phenomenon of the same kind with the Aurora Borealis; and that this earth would appear like a comet to a spectator placed in another planet.

The number of the comets is certainly very great, considerably beyond any estimation that might be made from the observations we now possess.

There are some,* who do not think the present astronomy of comets well established; and that as so many small ones are frequently seen, they think that nothing can be determined with certainty, till some better marks are discovered for distinguishing one from another, than any at present known; and that even the accomplishment of Dr. *Halley*'s prediction is uncertain: for it is very singular, that out of four years, in which three comets appeared, the only one, in which no comet was to be seen, should be that very year in which the greatest astronomers that ever existed had foretold the appearance of one; and, in accounting for its non-appearance, Mr. *Clairault* would have been equally supported by cometic evidence,* whether he concluded the comet to have been retarded or accelerated by the action of Jupiter and Saturn: a comet appeared in 1757, as well as in 1755, and had he determined the retardation of the comet to be twice as great as he did, another appeared in 1760 to have verified his calculations.

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* Encyclopædia Britannica, vol. ii. p. 765. Second Edition.

OF A PLURALITY OF WORLDS.

The fixed stars are generally supposed to be of the same nature with our sun, each of them attended by planets which are inhabited by rational creatures, like this earth.

Instead, therefore, of one sun, and one world, we find, that the region of unbounded space is peopled with suns, and stars, and worlds. This opinion has been held and taught by many of the most celebrated philosophers and astronomers, both in ancient and modern times: in this view of things, our system resembles a single individual of some one species of being in outward nature, diversified from all its fellow individuals, by differences unessential to the kind and species; but which constitute that beauty, which arises from uniformity amidst variety.

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* There does not indeed seem any evidence to prove the identical return of the same comet.

That the fixed stars are suns, shining by their own light, is probable, on account of their immense distance from us: for, as it is impossible that at these distances they could be seen by any reflexion of light from the sun, it is natural to suppose them endowed with a power of emitting light from their own bodies. By comparing the apparent diameter of objects at different distances, it is clear, that our sun would appear like a star, were he removed to the distance at which they are placed; and that therefore it is truly reasonable to suppose, that the fixed stars are equal, if not superior in magnitude, to that which is the center of our system; and that they are made for the same purposes with the sun, to bestow light, heat, and vegetation, on a certain number of planets revolving round them.*

Of their immense distance from us, and the vastness of the space they occupy, the reader may form some idea, when he is told, that numbers amongst them are at too great a distance to be adequately expressed by figures, and beyond the reach of admeasurement; and this will be heightened, if he considers, that the smallest of the stars visible to the eye are much more remote than the larger ones, and that the telescope discovers stars which are too distant to be perceptible to the naked eye: that the instrument, like our eyes, has its limits; but the extent of the heavens has no bounds.

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* Dr. *Herschel* closes his conjectures on the sun, &c. with the following general inference. "It seems therefore, on the whole, not impossible, that in many cases stars are united in such close systems, as not to leave much room for the orbits of planets or comets, and that consequently, upon this account also, many stars, unless we could make them mere useless brilliant points, may themselves be lucid planets, perhaps unattended by satellites."

EDIT.

The fixed stars being so far removed from, and for the most part invisible to us; it can scarcely be conceived by the narrowest mind, that they form a part of our system, or were created only to give a faint glimmering light to the inhabitants of this globe: for one additional moon would have afforded us more light than the whole host of stars; such an opinion is unworthy of our reason, inadequate to our conceptions of the Deity. It would be also absurd to suppose, that the Author of nature had made so many suns without planets, to be enlightened by their light, and vivified by their heat; but more so, to imagine so many habitable worlds enlightened by suns without inhabitants; we may, therefore, safely conclude, that all the planets, of every system, are inhabited.

This reasoning is still further strengthened, by considering the immensity of the starry heavens, in which are innumerable hosts of stars, created as the means to some great end. From revelation we learn, that the ultimate end of creation is the peopling of heaven with men. These resplendent suns are clearly then the mediums of existence to so many earths, and of men upon them, created to be happy eternally with their God, " the one eternal thirst to bless." " Every star is thus the center of a magnificent system, attended by a retinue of worlds, irradiated by its beams, and revolving round by its active influence." Thus the greatness of God is magnified, and the grandeur of his empire made manifest. He is not glorified on one earth, or in one world, but in ten thousand times ten thousand. " If we could wing our way to the highest apparent star, we should there see other skies expanded, other suns that distribute their inexhaustible beams of day; other stars that gild the alternate night, and other, perhaps nobler, systems established in unknown profusion, through the boundless dimensions of space. Nor does the dominion of the Sovereign of all things terminate here; even at the end of this vast tour we should find ourselves advanced no further than the frontiers of creation, the commencement of the great Jehovah's kingdom.*

This mode of reasoning applies with greater force to the planets of our own system, and gains additional strength from other considerations. For who would venture to assert, that infinite love and consummate wisdom had formed such immense material masses, some of which exceed our earth in size, convey them in revolutions round the sun, furnish them with moons, grant them the alternate changes of night and day, vicissitudes of seasons, and all this only to emit their scantly light on our earth.

Or who that has seen any engine, a windmill for instance, and who knows the use of it, if he travels into another country, and there sees an engine of the same sort, will not reasonably conclude that it is designed for the same purpose? So when we know that the use of this planet, the earth, is for an habitation of various sorts of animals, and we see other planets at a distance from us, some bigger, some less than the earth, moving periodically round, revolving on their axes, and attended with moons; is it not highly reasonable to conclude, that they are all designed for the same use as this earth is, and that they are habitable worlds like that we live in?

> Who can conceive them
> ———————— unpossess'd
> By living soul, desert and desolate,
> Only to shine, yet scarce to contribute,
> Each orb a gleam of light?

Or that the Almighty, who has not left with us a drop of water unpeopled, who has in every instance multiplied the bound of life, should leave such immense bodies destitute of inhabitants? It is surely much more rational to suppose them the possession of human beings, beings formed with capacities for knowing, loving, and serving their Amighty Creator; blest and provided with every object conducive to their happiness, and many of them in a far greater state of purity than the inhabitants of our earth, and therefore in possession of higher degrees of bliss, and placed in situations, furnishing them with scenes of joy, equal to all that poetry can paint, or religion promise: all under the direction, indulgence, and protection of infinite wisdom and goodness.*

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* *Hervey*'s Meditations.

The more the heavenly bodies excite our astonisment, from their size, their distances, the regularity of their motions, or any peculiarity or perfection we discover in those attractions by which they seem retained in their places, the more clear it is to any reasoning head, that they could not have made themselves: and that close connexion between cause and effect, which the farther we search the more clearly we discern, though it has staggered the faith of many a celebrated naturalist, is itself a proof, if he had not stopped short of the conclusion, that all these must have been the contrivance of consummate wisdom, and guided by an unerring hand.

Yet, at the same time, he who sees that every little corner of this earth of ours is replete with animal life, though but one race on it seems to be endowed with reasoning faculties, cannot but be led on to a conjecture at least, that all those vast bodies he discovers in the heavens may be peopled with their gradations of inhabitants likewise; and that each of them, not improbably, contains its rational beings too, to acknowledge and adore the Creator of them all. So far the heathen philosopher may go: though, if he be a modest inquirer after truth, he will not dogmatize, or enter into any particular detail of what is so totally out of his reach.

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* See the Rev. Mr. *Woolaston's* Reflexions.

LECTURE XLV.

ON PHYSICAL ASTRONOMY.*

THE causes of the celestial motions have in all ages been the objects of philosophical curiosity. Men have generally conducted their researches on this subject upon principles of analogy. Some resemblances have been noticed between the motions of the celestial bodies, and other motions nearer at hand, and more familiar to us; and the same resemblances have been supposed to exist between their causes.

I shall notice four of these different resemblances, or analogies.

1. The motions of the heavenly bodies have been thought to resemble the spontaneous motions of intelligent beings. *Aristotle*, *Leibnitz*, *Tucker*, *Monboddo*, and some others, both in ancient and modern times, have taught that the planets were conducted by spiritual intelligent beings.

Though accounts of the celestial phenomena may be given by means of this resemblance, that are chargeable with no false reasoning; yet as they afford no explanation, they answer no purpose in philosophy.

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* Professor *Robinson*'s Outlines of Mechanical Philosophy, p. 105.

2. The celestial motions have been thought to represent the motions of bodies carried about centers by means of solid connexions.

This notion suggested to philosophers the opinion, that the planets were attached to solid orbs, which turn round the axis of revolution: this opinion has been falsely attributed to *Aristotle*. It is altogether contradictory to our ideas of the etherial matter that occupies celestial space, and not easily reconcileable to the elliptic motion of the planets.

3. The celestial motions have been thought to resemble the motions of bodies carried round by a circulating fluid. Many philosophers have supposed the planets to be carried round in such vortices. *Descartes* and *Leibnitz* were at great pains to establish this doctrine. More modern writers* have removed the difficulties, and obviated the objections made to this system. It will therefore be necessary to lay before you some of the arguments urged in its favour; in doing this, I shall be under the necessity of repeating some of the observations that I have made before.

These writers urge, that so long as we keep within the limits of natural and experimental philosophy, we must account for the motions in nature, by referring them to corporeal causes; and where this cannot be performed satisfactorily, we must give them up, or wait with patience for some better clue of investigation, or some further light from experience. It is contrary to sound philosophy to amuse ourselves with names and qualities, which contradict the known laws of mechanism, and supersede the operation of the elements.

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* *Jones*'s Physiological Disquisitions; Essay on the First Principles of Natural Philosophy; Dr. *A. Wilson*'s Observations on the Moving Powers of the Present System.

Nothing is intelligible in philosophy but the action of matter upon matter; the power of impulse is the only sensible and experimental cause of motion; and there is the strongest presumption from analogy in favour of the universal material mechanism of the operations of nature. All other principles of motion are founded on conjecture, and incapable of proof. If you attempt to soar above this principle in theory, you are always obliged to descend to it in practice. Natural philosophy has been principally advanced by the experiments which have been made on the elements; but these experiments prove, that matter interferes in producing all the changes and motions that are observed in bodies distant from each other.

Look into, and observe the operations in nature: how does the sun act upon the fruits of the earth, but by the mediation of its light? How do the clouds water the earth, but by the mediation of air? How does the chemist produce such wonderful changes in natural bodies, but by the mediation of fire? In a word, every experiment, every observation proves, that in all cases where distant bodies are found to affect each other, there is always something to mediate, whether we do or do not perceive it; and when this mediation can be no further traced, natural philosophy is at an end, and the fictions of imagination begin, which are of equal value, by whatever name they may be called, or with whatever parade of demonstration they may be introduced.

It is very singular, they observe, that inquirers after physical truth should observe and acknowledge mechanism in the greater part of nature, and yet not be led thereby to inquire, whether it be not universally extended; the more so, as matter and motion must have the same invariable properties. If vapour rises mechanically, why may not a stone descend by the same law? If fluids circulate in organized bodies by continued impulse, why may not a planet revolve in the organized system of the universe by the same cause?

All true philosophers agree in considering the universe as a great machine, so created, fitted, and disposed by the power of God, as to perform all the operations, which are carried on throughout the whole. There is a connexion and communication between all the distant parts thereof. No one part can be considered as acting without being acted upon.

It is highly unphilosophical to assert, that matter, considered in general, or any part thereof, has essential separate qualities, by which one part acts upon another. It is the essential property of no one wheel in a machine to move its fellow, though, in consequence of its being placed in the station it is fitted for, it acts upon its fellow, because it is acted upon. If you interrupt the contact in a machine, you destroy the motion in all those parts where the communication is destroyed.

It is just the same with the whole system of nature, you cannot take up any parcel of matter and say of it, this has essential properties which empower it to be a natural agent. A philosopher ought to consider it as a concrete, with a certain disposition of parts liable to be acted upon by the subtiler parts of the machine, which can by no means be restrained by art therefrom. It might be as justly asserted, that it is the essential property of animal substances to live, as that it is the essential property of the loadstone to attract.

The promoters of the opinion now under consideration, urge further, that every known operation in nature is mechanical; and that in all experiments, where the explanation is clear and certain, the effects are produced by matter acting upon matter; and we are able to trace this mechanism in such a variety of instances, that unless the world is governed by opposite and contradictory principles, it must obtain throughout the whole.

Thus the body of man, which is the highest piece of machinery in nature, is made to see, to hear, and speak, upon mechanical principles; and it dies without a constant impression of a material force upon it from the element of air.

Again, from the pressure of air, the mercury is made to rise in the tube of the barometer. Hail, snow, and vapour, are formed in the atmosphere by the difference in its temperature; the clouds are sustained therein, and driven about to water the earth; plants grow and are nourished thereby.

For those effects where the cause is not so obvious, you find fire a more subtile agent, whose reality is proved, and its operations pointed out both by observation and experiment. It may be transferred from one parcel of matter to another. It will enter the pores, and fill the interstitial vacuities of all other substances. It acts with a force and velocity adequate to all the effects we can desire to ascribe thereto. It gives an elastic force to air, and occupies every space from which the air is exhausted. In some cases it acts as light, in others as fire; light, as it illuminates and renders objects visible; fire, as it burns and consumes what it acts upon.

Thus you find the fluid etherial matter of the heavens acting by impulse on the solid matter of the earth, being instrumental in every one of its productions, and necessary to every stated phenomenon of nature.

We are forced by the evidence of every phenomenon in nature, by every experiment in philosophy, to conclude, that impulse* is the only material cause of motion. All the properties of matter are such as fit them to act, and to be acted upon in a mechanical way. They are all such as can be adapted to the known principles of mechanism among artists. We are, therefore, bound by every rule of sound reasoning to consider it as the cause of all the motion, and continuance of motion, in the material universe. It is the one certain and only universal known cause. Neither the properties of matter, nor experiment, nor observation, afford any other.

No independent motion can be discovered. It is therefore wrong to consider the motion of any body abstractedly, or as a thing by itself. The system of nature is connected and related; and, to be understood, must be considered under those relations and connexions. Speculations which carry you out of the world, can never inform you how things are carried on in the world. Matter subsisting as a part of the created world has motion, but, if separated from the rest, would have no more motion than a limb divided from the body; and he who studies the nature of motion by taking matter abstractedly, is studying motion from that which has no motion belonging thereto.

Another strong argument adduced in favour of this system, is derived from the continuance and permanency of the motions observed in nature. That there is an universal principle of motion throughout the system of things, is self-evident. We know that matter moving can be the cause of motion in matter at rest; and we know of no other physical cause capable of producing such motion.

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* No mechanical motion can subsist without a plenum; this must be, wherever such mechanical motion subsists. This is so necessary a consequence of motion being carried on by impulse, that it needs no other demonstration.

Here, therefore, we must look for the causes of permanent motions.

Of the motion in different bodies, it is observable, that some retain the motion they have acquired, without any diminution, while others are soon reduced to a state of rest. When a body retains its motion without diminution, it is moved by such causes as would renew its motion, if it were stopped. When a cloud is flying before the sun, the same wind that drives it on, would restore its motion if it could be stopped. In the same manner the sails of a wind-mill, after you have brought them to a state of rest, and even confined them, will receive a new motion from the wind, as soon as the obstruction is removed. If you stop the motion of the lungs by an effort of the muscles, you find that the natural causes that act upon the body tend to renew the motion, and cannot be hindered from effecting it, without a considerable effort.

Every lasting motion is such a one, therefore, that will be renewed upon its own principles. This observation is of great importance towards accounting truly for the undecaying motions of the universe, to all which it may undoubtedly be extended: so that if it were possible to stop the planet Jupiter in his orbit, the established causes that act upon him, would renew his motion without any artificial motion.

A body continues to move as long as the natural causes of motion continue to act thereon; and rest, which is mechanical death, inevitably follows, when the causes of motion are no longer present. There may be subtile cases, in which it may be as hard for us to trace the causes of motion, as to shew why life remains for some time in an animal body under water without respiration. Still, however, the general assertion must be true, if every effect must have its cause; for then to every permanent effect there must be a permanent cause.

It is therefore not only absurd; but contrary to every analogy in nature, to suppose that any of the durable motions of the celestial bodies depend upon projection in a vacuum: because if you were to stop a body moved upon this principle, you have no means of renewing its motion, it must either fall into the sun, and thus come to a point of rest, or be dead and motionless for ever, without some miracle to give it a new motion; but this being contrary to the conditions of every undecaying motion; which will be renewed on its own principles in the ordinary course of nature, and by means already established, is not to be admitted into philosophy.

They further urge as a reason for rejecting the hypothesis of a projectile impulse, that it obliges its supporters to make the universe a vacuum: because those elements which are ordained to act upon matter, and keep up the life and motion of the world, would stand in the way, hinder the freedom, and disturb the operation of an imaginary principle, projection. They consider projection not only as an hypothetical, but as an artificial and unnatural principle, that cannot be proved to obtain any where in nature. If it be received, they say it must be received as an article of faith.

Experiments have been made with a central force machine, to illustrate the doctrine of centripetal and centrifugal forces.* But they by no means apply to any case in nature, for the moving body is always connected by a line to its center of motion; a circumstance that never can be reconciled to motion in a vacuum, where no connexion is supposed; nay, is even objected to upon principle. But these experiments are still further deficient, because the centrifugal force being a consequence of, or derived from the artificial revolution of the whirling body, cannot be used as a cause of the motion: for it is the nature of all causes to be prior to their effects, but here it is posterior; the body is never disposed to fly off in a tangent till it has acquired its revolution. This force can, therefore, never be applied to account for any of the celestial motions, because it brings us to this absurdity, that there is nothing to account for the motion, but the motion itself, or the consequence of the motion.

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* The machine here alluded to, is the whirling table; the description of which I have given in vol. iii. p. 362, et seq. It is a machine, in my opinion, of a very evident and illustrative nature, shewing by experiments the laws of central, &c. forces, whatever may be the real cause of motion. EDIT.

The same objections apply to another illustration, namely, casting round a weight suspended in a sling, and even further; for the power of the sling restraining the body from flying off in a tangent, bears no analogy to a power actually drawing the moving body towards its center of motion.

It has been objected to this reasoning, that no body can move in a space filled with matter, commonly called a *plenum.* But this entirely depends on the condition of the matter and the circumstances of the moving body: if the matter filling the space be a fluid, whose parts can easily slide over one another, they will be able to move in different or contrary directions at the same time, and while the place of the whole mass remains the same, the place of the parts of which it is composed may be continually changing.

The fulness of the space is therefore no objection to the free motion of the parts of any fluid among themselves; neither is it any objection to the motion of any solid body in such a fluid medium. Though a vessel be filled with water closely stopped, and the fluid so compressed, that a very small point made to enter therein would burst the containing vessel, yet any solid will move freely therein from one side to the other, or from the top to the bottom; because the parts of the fluid which are displaced before, fall into that space behind quitted by the body. So fast as the body proceeds, just so fast do the parts of the fluid recede; so that there is neither impediment nor vacuity. The same is true in other cases; there may be motion, provided there be a circulation among the parts.

When a solid body is moved in a fluid by any artificial force or violence, contrary to the nature of the medium in which it moves, the parts of the medium, by endeavouring to recover their natural state, will resist the motion of the body till the equilibrium is restored, and the body is at rest. Such will necessarily be the case of all violent motions; it is soon destroyed by resistance, though the time in which it is destroyed may differ from a variety of circumstances.

But, on the other hand, if the motion of the body arises from the motion of the medium in which it moves, then the resisting nature of the medium is no longer an objection to the motion of the body, neither can it be, for it is the cause of its motion; and it is absurd to suppose, that the cause of a motion can resist the motion it causes. No inference, therefore, from the resistance of mediums can lead us to the necessity of a vacuum. A vacuum is only necessary when a motion is proposed, which is independent of the action of every medium; but nature knows of no such motion.

A variety of motions may be exhibited, for whose production the presence of a resisting medium is absolutely necessary; and they shew, that so far from a vacuum being necessary to the continuance of motion in any space, the motion is promoted and occasioned by a resisting medium. That hypothetical train of reasoning which leads us to conclude, that if less matter were in the space, the motion would be more free and continue much longer, is as unphilosophical, as it would be if, in order to enable a man to run faster, we should rid him of the incumbrance of his boots and spurs, by cutting off his legs.

Air is, you know, a resisting medium, yet, instead of retarding the motion of the lamp machine, which I before shewed you, by its resistance preserves that motion; and if the motion be at last discontinued, it does not arise from defect or irregularity of the cause, but from the imperfection of the materials. If the materials which are acted upon would but continue in the same state, the motion would be unretarded as long as air and fire, which are the causes thereof, subsist in the world. In this experiment the causes are not artificial and violent, as in the central force machine, but such as are supplied by nature itself, in its regular mode of action; which both begins and continues the motion. What is performed by the agents in nature in the one case, may certainly be done in others. The planets may be carried round in their orbits by the same means. The heavens may be filled throughout with an etherial fluid, not infinitely rarefied, unresisting, and impotent; but dense and continuous in its parts.

The writers in favour of the mechanical system urge, that their opponents have no notion or means of resolving their axioms, or relative laws of motion, to mechanism, but consider them merely as laws; another word, as they use it, for ultimate, spiritual, unmechanical power. As the penetration of some amongst them has carried them so far as to suppose an impelling etherial medium for maintaining attraction, gravitation, &c. &c. it is rather surprizing that they could not perceive that the same medium was necessary for supporting their laws of motion, rest, resistance, &c. for the difficulty does not lie in accounting for gravitation, or any particular kind of motion, but in finding powers to produce and maintain motion in general. If these are mechanical, it is easy to suppose, that the contriver may have adjusted the mechanism so as to produce the particular tendencies. But if they are unmechanical, you may call them laws, properties, or any other name, either with or without a meaning. How detrimental it is to the increase of knowledge in the powers and agency of nature, to have the most curious productions of these powers reduced to unintelligible laws, characterized by words without meaning, and which render their inventors no wiser than the most heedless and unattentive!

Without instrumental, or second causes, there can be no regular course of nature; and without a regular course, nature could never be understood. The order and course of things, and the experiments we daily make, shew that there is a mind that governs and actuates this mundane system, as the proper real agent and cause; the inferior and instrumental cause seems to be fire; with respect to attraction, it cannot produce, and in that sense account for the phenomena, being itself one of the phenomena produced and to be accounted for. What is said of forces residing in bodies, whether attracting or repelling, it can only be considered as a mathematical hypothesis, not as any thing real and existing in nature.

The mechanical agency of the elements accords with the descriptions and allusions of the sacred scriptures. The heathens were in some degree acquainted therewith. When this doctrine was in their hands, a principle of intelligence was ascribed to the active elements, and they were taken for the Gods who govern the world. But with those who are taught that the True God is distinct from, and above the world of matter, though virtually present by a providential inspection and superintendance, it serves only to enlarge and exalt their ideas by setting before them the visible evidence of divine wisdom, which with so exquisite a contrivance, and such simplicity of design, hath adapted physical causes to the production of their respective effects.

We have now to consider, 4thly, the mathematical principles of philosophy. The celestial motions have been thought to resemble those exhibited to us in the phenomena of magnetism and electricity; these and the celestial bodies seem to act upon each other at a distance, without any observed intervening impulse. Accordingly, many philosophers, both ancient and modern, have imagined that the planets are influenced by causes similar to those of these more familiar phenomena. But these philosophers had formed no accurate notions of the agency of the causes of the motions from which they attempted to derive an explanation; neither had they examined attentively the circumstances of the motions which they attempted to explain. At last, Sir *Isaac Newton* contented himself with an investigation of the laws observed in the agency of the causes of the celestial motions, discovered that these laws were the same with those observed in the agency of the causes of the motion of common heavy bodies, and from this discovery gave a theory of mathematical astronomy. We are indebted, however, to *Kepler* for the generalization of facts, which form the basis of the mathematical theory.

KEPLER'S LAWS.

Kepler's first law is, *that the planets, in revolving round the sun, describe equal areas in equal times.*

Kepler's second law is, *that the orbits described by the planets are ellipses, having the sun or the primary planets in the focus.*

Kepler's third law is, *that the squares of the periodical times of the planets are as the cubes of their mean distances from the sun.* That is, as the square of the time which a planet, A, takes to revolve in its orbit, is to the time which any other planet, B, takes to run through its orbit; so is the cube of the mean distance of A from the sun, to the cube of the mean distance of B from the sun.

OF DEFLECTING FORCES.*

In consequence of the inertia of matter, all motion is considered as equable and rectilineal, and as being in a straight line with the direction of the moving force; and as preserving this direction until it be hindered or put out of its way by some extrinsic cause.

If therefore a body moves in a curve, that curvature must proceed from some external force continually acting upon the body; and whenever that force ceases to act, the body will move forward in a right line, touching the curve in that point where the body is at the instant of time when the force ceases to act.

When you observe a change in the direction of any motion, you may infer the action of a force, whose direction crosses that of the former motion. This may be called a *deflecting force.*

The change of direction is measured by the angle contained between the former and the new direction.

When the motion of a body is curvilineal, the deflexion is continual, and you may infer the continual action of a deflecting force. On the other hand, the continual action of a deflecting force produces a curvilineal motion.

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* Professor *Robinson*'s Outlines of Mechanical Philosophy, p. 34 to 107.

In a curvilineal motion the change of direction is measured by the angle contained between the tangents to the curve.

A curvilineal motion is therefore always a compound motion; but the great bodies of this system, as the planets, move round the sun in curve lines; on these principles, there must therefore necessarily be two powers acting on them; one impelling them to move in a straight line, the other deflecting or bending them continually towards a center.

You may, therefore, consider deflecting forces as always directed to or from a point; in the first case they are called *centripetal* forces, in the second case they are called *centrifugal* forces. In general, they are termed *central* forces; and the point, through which their direction always passes, is called the center of the forces.

Among the various curvilinear motions which may arise from the action of central forces, there is a circumstance in which they all agree, and which enables the mathematician to investigate the forces by which they are produced.

If a body moves in a curve line, A B C D E F, *plate* 15, *fig*. 3, by means of a force always directed to a fixed point S, the curve is all in one plane, and the areas, A S B, A S C, A S D, described by the straight line joining the body with the point S, are proportional to the times of description; *i. e.* equal areas are described in equal times, unequal areas in unequal times. Thus the triangular areas A S B, B S C, C S D, &c. described by the straight line joining the body with the point S, are proportional to the times of description.

Let the time be divided into equal parts, let the body be acted on by an impulse that will carry it from A to B, the first given particle of time; then in the second particle it would go an equal space, and describe the line B c, equal to the line A B.

But when the body is arrived at B, let a deflecting centripetal force so act upon it, that while its first impulse would carry it to c, the deflecting force would carry it to V; complete the parallelogram B V C c, and it is evident from the doctrine of compound forces, that the body would in the second particle of time describe the diagonal B C.

Now, as C c is parallel to S V, the triangles S B C, S B c, are between the same parallel lines, and as such, are by geometry proved to be equal; for the same reason the triangles S C D, S E F, are proved to be equal to S B A.

If any number of these triangles be added together, the total sums, as A D S, F C S, will be proportional to the times wherein they are described.

If the lines, A B, B C, be continued round a center, they will form a polygon, and if the sides of the polygon be indefinitely increased in number, and indefinitely decreased in length, they will form a curve, a circle, or an ellipsis: and the proposition will be true of these curves, that a line drawn from the center to a body in the circumference of the circle, or from the focus to a body in the circumference of the ellipsis, will sweep equal areas in equal times.

The power, therefore, directed towards the given point S, has no effect on the magnitude of the area described by the line supposed to be drawn from the body to that point. It may accelerate or retard the motion of the body, but affects not the area or space described by the line. The line will still continue to describe the same spaces in equal times, about the given point, as it would have done if no new force had acted on the body, but it had been permitted to proceed uniformly in the line of projection.

As one impulse towards the given point has no effect on the area or space described by the ray or line from the body to that point, so any number of successive impulses directed to the same point can have no effect on the area; and if you suppose the power directed to that point, to act continually, it will bend the way of the body in motion into a curve, and may accelerate or retard its velocity, but can never affect the area described in a given time by a line supposed to be drawn from the body to the given point, which will always be of an invariable quantity, equal to that which would have been described in the same time, if the body had proceeded uniformly in a right line from the beginning of the motion.

The converse of the foregoing proposition shews, that if a body, A, describes a curve all in one plane, and if there be a point, S, so situated in this plane, that a line drawn therefrom to the circumference describes proportional areas in proportional times, then is the body urged round by a force tending towards that center. In other words, the equable increase of the areas described by a line drawn from a body to a given point, is an indication that the direction of the power that acts upon the body, and that deflects it into a curve, is directed to that point.

By the same proposition we may illustrate and explain the revolutions of the primary planets in elliptical orbits, not much differing from circles, round the sun, who is in one of the foci of each ellipsis.

Let the ellipsis ABCDEFGHIKLM, *plate* 15, *fig.* 4, represent the orbit of a planet moving therein round the sun S, according to the order of the letters, the sun, S, being in one of the foci of the ellipsis; let the time of its revolution be divided into any number of equal parts, suppose twelve, in moving from A through B C D, &c. the planet approaches nearer the sun, and the central tendency continually increasing its velocity, it goes through greater arcs in equal times, till it comes to G; from thence its motion continually carries it to a greater distance from the sun, and it describes in equal times smaller and smaller arcs, till it returns to A, from whence it proceeds as before.

Now, the triangular spaces passed over by a line drawn from the planet to the center of the sun will be equal, because in the planet's going the first half of the ellipsis from A to G, the arcs which may be considered as the base of the mixed triangles described in equal times, grow longer and longer, as the legs grow shorter, so as to preserve the equability of the triangular space: in the other half of the ellipsis, in the planet's going from G to A, the arcs grow shorter; but this is compensated by the greater length of the legs.

The sum of what has been proved is: 1. That the areas or spaces revolving round an immoveable center are proportional to the times; and, 2. That if a body revolving round a center describes about it areas proportional to the times, the body is actuated by a force directed to that center.

But, by *Kepler*'s first law, we know, " that the primary planets describe round the sun, and the secondary planets describe round their respective primary planets, areas proportional to the times." From hence it is inferred, that the primary planets are retained in their orbits by forces which are always directed to the sun; and that the secondary planets are retained in their orbits round their primary planets by forces which are always directed to those primary planets.

Kepler's second law is, " that the orbits described round the sun, and round the primary planets, are ellipses, having the sun or the primary planet in the focus." From hence it is inferred, that the accelerating force, by which a planet is retained in the different parts of its elliptical orbit, is inversely proportional to the square of its distance from the sun, or from its primary.

Kepler's third law is, "that the square of the periodic times of planets revolving round common centers, are proportional to the cubes of their mean distances." From this it is inferred, that the forces by which the planets are retained in their different orbits, are inversely proportional to the squares of their distances from the sun. The same reasoning applies to the satellites.

Hence it is also inferred, that the forces by which different planets are retained in their different orbits, are not forces of different kinds, but the same force operating at different distances.

The secondary planets accompany the primary planets by the action of a force always directed to the sun, and inversely proportional to the square of the distance from the sun.

*That the moon is a heavy body, and gravitates towards the earth in the same manner as terrestrial bodies.**

Sir *Isaac Newton*, considering that the power of gravity acts equally on all matter that is in or near the surface of the earth, that it is not sensibly less on the tops of the highest mountains, that it affects the air and reaches upward to the utmost limits of the atmosphere, was induced to think it might be a more general principle, and extend to the heavens, so as to affect the moon at least, which is the nearest to us of all the bodies in the system. He afterwards extended this principle still further, and shewed, that the planets consisted of the same gravitating substance of which the earth is formed.

These effects of the power of gravity upon terrestrial bodies may be reduced to three classes. 1. When in consequence thereof, a body at rest, supported by ground, suspended by a string, or any otherways kept from falling, endeavours always to move. In such cases the effect of gravity is measured by the pressure of the quiescent body upon the obstacle that hinders its motion.

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* *Maclaurin's* Sir Isaac Newton's Discoveries, p. 214 to 265.

2. When a body descends in a vertical line, its motion is then continually accelerated, in consequence of the incessant action of the power of gravity; or if it be projected upwards in the same right line, its motion is continually retarded by the same power acting incessantly upon it in a contrary direction. In such cases the power of gravity is measured by the acceleration or retardation of the motion produced in a given time by the power continued uniformly for that time.*

3. When a body is projected in any direction different from the vertical line, the direction of its motion is continually varied, and a curve line is described in consequence of the incessant action of gravity; which in such cases is measured by the flexure or curvature of the line described by it; for the power must be the greatest that deflects the course of the body most from the tangent or direction in which it was projected.

Effects of each kind of the power of gravity continually fall under your observations near the surface of the earth; for the same power which renders bodies heavy while they are at rest, accelerates their motion when they descend perpendicularly, and bends their motion into a curve line when they are projected in any other direction than that of their gravity.

We can judge only of the powers that act on the celestial bodies by the effects of the last kind; we see bodies near the earth falling towards it; but this is a proof of the moon's gravity, which cannot be obtained unless the present state of things were dissolved.

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* See Lecture on Mechanics.

When a body is projected in the air, you do not see it fall in the perpendicular towards the earth, but you see it falling every moment from the tangent to the curve, that is, from the direction into which it would have moved, if its gravity had not acted for that moment.

And this proof is obtained of the moon's gravity; for though you do not see her falling directly towards the earth in a right line, yet you observe her every moment descending towards the earth from the right line, which was the direction of her motion at the beginning of that moment, and this is as evident a proof of her being acted upon by gravity or some power similar to it, as her rectilineal descent would be, if she were allowed to fall freely to the earth.

If we were in possession of engines of a sufficient force, bodies might be projected from them so as not only to be carried a vast way without falling to the earth, but so as to move over a quarter of a great circle thereof; or, abstracting from the resistance of the air, to move round the earth without touching it, and after returning to the first place, commence a new revolution with the same force which they first received from the engine, and after that a third, and thus revolve as a moon or satellite round the earth for ever.

If this could be effected near the earth's surface, it might be done higher in the air, or even as high as the moon, could the engine or an equivalent power be carried up and made to act there. By increasing the force of the power, a body proportionally larger might be thus projected, and by a power sufficiently great, a body not inferior to the moon, might be at first put in motion, and being perpetually restrained by its gravity from going off in a straight line might for ever revolve about the earth.

Thus Sir *Isaac Newton* saw, that the curvilineal motion of the moon in her orbit, and of any projectile at the surface of the earth, were phenomena of the same kind, and might be explained upon the same principle extended from the earth, so as to reach the moon; and that the moon was only a larger projectile that received its motion in the beginning of things from the Almighty Author of the universe.

But to make this more evident, it was necessary to shew, that the powers which act on the moon, and on projectiles near the earth, and which bend their motions in a curve line, were directed to the same center, and agreed in the quantity of their force as well as in their direction.

All we know of force relates either to its direction or quantity, and a constant coincidence or agreement in these two respects is sufficient ground to conclude them to be the same, or similar phenomena, derived from the same or like causes.

Now I shewed you, in the Lecture on Mechanics, that the gravity of heavy bodies is directed towards the center of the earth; and it appears from *Kepler*'s first law, as I have shewn you in this Lecture, that the power which acts on the moon, incessantly bending her motion into a curve, is directed towards the same center; for astronomers find, that the moon does not describe an exact circle about the earth, but an ellipse, and that she approaches to the earth, and then recedes from it in every revolution, but still so as to have her motion accelerated while she approaches to the center of the earth, and retarded as she recedes from it, describing equal areas in equal times; an indication, as you have already seen, that she is acted on by a power directed accurately or nearly towards the center.

There is, therefore, a power which deflects the moon from a rectilineal course, and which, like gravity, makes her descend towards the center of the earth; so that if the projectile force were destroyed, she would fall to the earth in a direct line; and as this power acts incessantly, bending every moment her path into a curve, it would make her descend to the earth with an accelerated motion, like that of heavy bodies in their fall.

It remains therefore only to shew, that the power which acts on the moon, agrees with gravity in the quantity of its force, as well as in other respects. But before we compare them in this particular, I must observe to you, that the power which acts upon the moon, is not the same at all distances, but is always greatest when she is nearest the earth.

To be satisfied of this, it is only necessary to observe, as before, that to bend the motion of a body into a curve when it moves with a greater velocity, requires more power than when it describes the same curve with a less velocity.

Though what I have just asserted is sufficiently obvious, it may appear more fully by considering a diagram; imagine therefore a tangent, *plate* 15, *fig*. 5, drawn at the beginning of a small arc described by the body; and as this is the line which the body would have followed, if no new power had acted upon it, the effect of that power is estimated by the depression of the other extremity of the arc under that tangent: now it is plain, that in arcs of the same curvature, the greater the arc is, the farther must one extremity of it fall below the tangent drawn at the other extremity; and, consequently, when a body describes a greater arc, it must be acted upon by a greater power than when it describes a less arc in the same time. Now, as the moon approaches the earth, her motion is accelerated, is swiftest at her least distance, slowest at her greatest distance; and the force she describes at her greatest and least distance have the same curvature; therefore the force which acts upon her at her least distance, when her motion is swiftest, must be the greatest force.

It will not now be difficult to see according to what law this power varies at her least and greatest distance from the earth. To render this easier, let us assume a simple case, and suppose that her least distance is half that of her greatest. If this were true, the moon would move with double velocity in her least distance; and the space described by a ray from her to the earth might be equal to the space described in the same time at her greatest distance; so that she would describe at her least distance an arc in one minute equal to the arc she would describe in two minutes at her greatest distance, and would fall as much below the tangent at the beginning of the arc in one minute in the lower part of her orbit, or the perigee, as in two minutes in the higher part of her orbit, or her apogee.

If, therefore, her projectile force was destroyed at her least distance, she would fall towards the earth as much in one minute, as in two minutes if her projectile force was destroyed at her greatest distance.

But the spaces described by a falling body are as the squares of the times, and such a body descends through a quadruple space in double time; so that the moon descending freely would necessarily fall four times as far in two minutes as in one minute; that is, through four times as much space in one minute at her least distance, as at her greatest distance in the same time.

But the forces with which heavy bodies descend are in the same proportion as the spaces described, in consequence of those forces, in equal small parts of time; consequently, the force which acts at the least distance is quadruple that which acts at a greater distance, when the latter is supposed to be double the former; or the forces are as 4 to 1, when the distances are as 1 to 2. The force therefore which acts upon the moon, and bends her into a curvilinear orbit, increases as the distance from the center of the earth decreases, so as to be quadruple at half that distance.

In the same manner it is shewn, that if her least distance was the third part only of her greatest distance, her velocity would be triple at the least distance, to preserve the equability of the areas described by a ray drawn from her to the center of the earth; and that she would be acted upon there by a power, which would have the same effect in one minute, as in three minutes at her greatest distance; so that if she was allowed to descend freely from each distance, she would fall nine times as far from the least distance as from the greatest in the same time; consequently, the power itself which causes her to descend would be nine times greater at the third part of the distance, or the distances being as 1 to 3, the force would be as 9 to 1, or inversely as the squares of the distances.

In the same manner it appears, than when the greatest and least distances are supposed to be in any proportion of a greater to a less number, the velocities of the revolving planet are in the inverse ratio of the same numbers; and that the powers which deflect or bend its motion into a curve, are in the inverse ratio of those numbers.

To consider this in general, let T, *plate* 15, *fig.* 5, represent the center of the earth, ALP the moon's elliptical orbit, A the apogee, P the perigee, AH and P K the tangents at those points, AM and P N any small arcs described by the moon in equal times at those distances, M H, N K, the subtenses of the angles of contact, terminated by the tangents in H and K; then M H and N K will be equal to the spaces that would be described by the moon, if allowed to fall freely from the respective places A and P in equal times; and will be in the same proportion to each other, as the powers which act upon the moon, and inflect her course at those places.

Let Am be taken equal to P N, and m h parallel to AP meet the tangent at A in h; now, as the curvature of the ellipse is the same at A as at P, m h is equal to K N; and if the moon was to fall freely from the places P and A towards the earth, her gravity would have a greater effect at P than at A, in equal times, in proportion as m h is greater than M H. But m h is the space which the moon would describe freely by her gravity at A, in the time which m h would be described by her projectile motion at A, and M H is the space through which she would descend freely by her gravity at A, in the time in which AH would be described by her projectile motion; and these spaces being as the squares of the times, it follows, that m h is to M H, as the square of Ah to the square of AH, or, because of the equality of the areas TAH, TPK, as the square of TP to the square of TA.

Therefore, the gravity at P is to the gravity at A, as the square of TA to the square of T P; that is, the gravity of the moon towards the earth increases in the same proportion, as the square of the distance from the center of the earth decreases.

Sir *Isaac Newton* shews the universality of this law, in all her distances, from the direction of the power that acts upon her, and from the nature of the ellipsis, the line which she describes in her revolution; and it follows from the properties of this curve, that if you take small arcs described by the moon in equal times, the space by which the extremity of any arc descends towards the earth below its tangent at the other extremity, is always greater in proportion as the square of the distance from the focus is less; from which it follows, that the power which is proportional to this space observes the same proportion.

The moon's orbit, according to astronomers, differs not much from a circle of a radius equal to 60 times the semidiameter of the earth; and the circumference of her orbit is therefore about 60 times the circumference of a great circle of the earth.

From this the circumference of the moon's orbit is easily computed, and as she finishes her revolution in 27 days, 7 hours, and 43 minutes, it is also easy to calculate what arc she describes in one minute.

The next thing is to compute how much this arc of one minute is deflected below a tangent drawn at the other end: now geometricians prove, that this space is nearly a third proportional to the diameter of her orbit, and the arc she describes in a minute; whence, by an easy calculation, this space is found to be about 16 feet 1 inch.

But you have seen, that this space was described in consequence of her gravity, or tendency towards the earth, which is therefore a power, that at the distance of 60 semidiameters of the earth, is able to make her descend in one minute through 16 feet 1 inch.

Now, as this power increases as she approaches the earth, let us see what its force would be at the surface thereof; and for this purpose, let us suppose her to descend so low in her orbit as at her least distance to pass by the surface of the earth; she would then be 60 times nearer to the center of the earth, and move with a velocity 60 times greater, that the areas described by a line drawn from her to that center in equal times, might still continue equal.

The moon, therefore, passing by the earth at her lowest ebb, would describe an arc in one second of time, the 60th part of a minute, equal to that she describes in one minute at her present mean distance, and would fall as much below the tangent at the beginning of the arc in a second, as she falls from the tangent at her mean distance in a minute; that is, she would fall near the surface of the earth 16 feet 1 inch in 1 second of time.

Now this is exactly the same space, through which all heavy bodies are found by experience to descend by their gravity near the surface of the earth. The moon, therefore, would descend at the surface of the earth with the same velocity, and every way in the same manner, as heavy bodies fall towards the earth; and the power which acts upon the moon, agreeing in direction and force with the gravity of heavy bodies, and acting incessantly every moment, as their gravity does, they must be of the same kind, and proceed from the same cause.

Thus Sir *Isaac Newton* shewed, that the power of gravity is extended to the moon; that she is heavy, as all bodies belonging to the earth are found to be; and that she is retained in her orbit by the same cause which occasions a stone, a bullet, or any other projectile, to describe a curve in the air. If the moon or any part of her were brought down to the earth, and projected in the same line, and with the same velocity as a terrestrial body, it would move in the same curve. On the other hand, if any body was carried from our earth to the distance of the moon, and was projected in the same direction, and with the same velocity with which the moon is moved, it would proceed in the same orbit which the moon describes, and with the same velocity. Thus the moon is a projectile, and the motion of every projectile gives an image of the motion of a satellite or moon.

That the primary planets are heavy bodies, and gravitate towards the sun; and that the secondary planets gravitate towards their respective primaries.

Observation proves, that each of the primary planets bend their path about the center of the sun, are accelerated as they approach to him, and are retarded as they recede from him, always describing equal areas in equal times; from whence it follows, that the power by which they are deflected must be directed to the sun. This power also varies always in the same manner as the gravity of the moon towards the earth.

The same reasoning, by which the gravity of the moon towards the earth at her greatest and least distances were compared together, may be applied in comparing the powers which act on any primary planet at its greatest and least distances from the sun; and it will appear, that these powers increase as the square of the distances from the sun decrease.

But the universality of this law, and the uniformity of nature, still further appear, by comparing the motions of the different planets.

The power which acts on a planet that is nearer the sun, is manifestly greater than that which acts on a planet more remote, both because it moves with more velocity, and because it moves in a less orbit, which has more curvature, and of course the body requires more force to be more deflected from its rectilinear course. By comparing the motions of the planets, it is found, that the velocity of a nearer planet is greater than that of one more remote, in proportion as the square root of the number expressing the greater distance, to the square root of the number expressing the lesser distance; so that if one planet be four times farther from the sun than another planet, the velocity of the first would be half the velocity of the latter, and the nearer planet would describe an arc in one minute equal to the arc described by the higher planet in two minutes; and the nearer planet would describe, by its gravity, four times as much space as the other would describe in the same time; by the law of falling bodies, the gravity of the nearer planet would therefore apappear to be quadruple, from the consideration of its greater velocity only. But further, as the radius of the lesser orbit is supposed to be four times less than the radius of the other, the lesser orbit must be four times more curve, and the extremity of a small arc of the same length will be four times farther below the tangent drawn at the other extremity in the lesser orbit than in the greater; so that though the velocities were equal, the gravity of the nearer planet would on this account only be found to be quadruple.

On both these accounts together, the greater velocity of the nearer planet, and the greater curvature of its orbit, the deflecting force, or its gravity towards the sun, must be supposed sixteen times greater, though its distance from the sun is only four times less than the other; that is, when the distances are as 1 to 4, the gravity is reciprocally as the squares of these numbers, or as 16 to 1. By comparing the motions of all the planets it is found, that their gravities decrease as the squares of their distances from the sun increase.

The same principle that governs the motion of the planets in the great solar system, governs also the motion of the satellites in the lesser system, of which the greater is composed.

There is the same harmony in their motions compared with their distances, as in the great system. Jupiter's satellites are continually bent from the lines that are the direction of their motions, each describing equal areas in equal times, by a ray drawn to the center, to which their gravity is therefore directed.

The nearer satellites move with greater celerity, in the same proportion as the nearer primary planets move more swiftly round the sun; and their gravity therefore varies according to the same law. The same is to be said of Saturn's satellites.

There is, therefore, a power that preserves the substance of these planets in their various motions, acts at their surfaces, and is extended around them, decreasing in the same manner as that which is extended from the earth and sun to all distances.

They accompany their primary planets in their motion round the sun, and move about them at the same time, with the same regularity as if their primaries were at rest. It is as in a ship, or in any space carried uniformly forward, in which the natural actions of bodies are the same as if the space was at rest, being no way affected by that motion which is common to all the bodies.

As every projectile, while it moves in the air, gravitates towards the sun, and is carried along with the earth about the sun, while its own motion in its curve is as regular as if the earth were at rest; so the moon, which is only a greater projectile, must gravitate towards the sun, and while it is carried along with the earth about the sun, is not hindered by that motion from performing its monthly revolutions towards the earth. It is the same with respect to the other secondary planets.

Thus the motions in the great solar system, and in the lesser particular systems of each planet, are consistent with each other, and are carried on in a regular harmony, without any confusion or mutually interfering with one another, except what necessarily arises from small inequalities in the gravities of the primary and secondary planets, and the want of exact parallelism in the direction of these gravities.

Observation shews, that the deflexion of the moon to the earth, and of the planets to the sun, is accompanied by an equal and opposite deflexion of the earth to the moon, and of the sun to the planets; from which it is inferred, that the forces which produce these deflexions are mutual, equal, and opposite.

As the planets are deflected towards each other, and as these deflexions are inversely proportional to the square of the distance from the planet towards which they are inflected; it follows, that all the bodies of the solar system turn towards each other with forces which are inversely proportional to the square of the distances.

The curve which a body describes determines the law of its gravitation, or the relation which subsists between the intensity of the gravitating force, and the distance from the point to which it gravitates.

If the gravitation of every particle of gravitating matter is supposed to be the same in the same circumstances; then the relation which is observed between the distances and the periodic times, will determine the proportion of gravitating matter in a planet; and on this supposition it has been concluded from the phenomena, that this proportion is the same in all. But as this supposition is not formed from any direct arguments, all that can be justly inferred from this observed relation is, that the gravitation of each planet, taken *in cumulo*, is proportional to its quantity of gravitating matter.

OF THE CENTER OF THE SOLAR SYSTEM.

Sir *Isaac Newton* having found, that the celestial bodies gravitate towards each other, and towards all other bodies in the system, neither of them, nor indeed any body in the whole system can be supposed to be void of all motion.

The center of gravity of the whole system is the only point therein, which can be supposed quiescent; it is the only immoveable point, round which all the bodies in the system move with various motions.

On an accurate examination of the tendencies of the planets, it is found, that the center round which each planet revolves, is not the center of the sun, but the point which is the common center of gravity of the sun and planet, whose revolution is considered. Thus, the mass of the sun being to that of Jupiter as 1 to $\frac{1}{1067}$, and the distance of Jupiter from the sun being to the sun's semidiameter in a ratio somewhat greater, it follows, that the common center of gravity of Jupiter and the sun is not far distant from the surface of the sun.

By the same method of reasoning it is found, that the common center of gravity of Saturn and the sun falls within the surface of the sun; and also, that if all the planets were placed on the same side of the sun, the common center of gravity of the sun and all the planets, would scarce be one of his diameters distant from his center.

It is about this center of gravity that the planets revolve; and the sun himself oscillates round this center in proportion to the actions of the planets exerted on him.

When, therefore, the motion of two bodies, whereof the one revolves round the other, is considered rigorously, the central body should not be regarded as fixed, as they both revolve round their common center of gravity; but the spaces they describe round this common center being in the inverse ratio of their masses, the curve described by the body which is the greatest mass, is almost insensible; for which reason, the curve described by the body, whose revolution is sensible, is only to be considered, and the small motion of the central body, which is regarded as fixed, is neglected.

The earth and the moon, therefore, revolve round their common center of gravity, and this center of gravity revolves round the center of gravity of the earth and sun. The case is the same with Jupiter and his moons, Saturn and his satellites, and with the sun and all the planets. And the sun, according to the different position of the planets, moves successively on every side around the common center of gravity of our planetary system.

This center is the point where all the bodies of our planetary system would meet, if their projectile forces were destroyed, though the sun is in perpetual agitation, being, as I have shewn to you, so near it, he may with propriety be considered by astronomers as the center of the solar system.

Gravity produces some small irregularities in the motion of the planets.

The regularity of the planetary motions is disturbed by their mutual gravitation, each disturbing the motions of the other, with a force proportional to its quantity of matter directly, and to the square of its distance from them inversely. In order to calculate these disturbances, it was necessary for mathematicians previously to ascertain the quantity of matter in the sun and planets.

When a fleet of ships is carried away by a current that affects them equally, it has no effect on their particular motion amongst themselves, nor is the motion from the current discovered by them, unless they have some body in sight, that is not affected thereby in the same manner. The regularity in the motions of a planet, A, round the sun, would not be disturbed by the gravitation to a planet B, if the sun, and the planet A, did gravitate to B with equal forces, and in parallel directions; and the disturbance of the motion A, arises from the inequality and obliquity of the gravitations of the sun, and of A and of B.

In consequence of this disturbing force, the motion of the earth in its orbit is retarded from the time that Jupiter is in opposition to the time that he is in quadrature with the sun. It is then accelerated till he is in conjunction, then retarded till he is in quadrature, and then accelerated till he is again in opposition.

The earth's gravitation to the sun is increased while Jupiter is in or near the quadratures, and diminished while he is in or near the conjunction and opposition.

The augmentation of the earth's gravitation to the sun is greatest when Jupiter is in quadrature, being then about $\frac{1}{25000}$ of the whole gravitation to the sun. The diminution of the earth's gravitation to the sun is greatest when Jupiter is in opposition, being then about $\frac{1}{10000}$ of the whole gravitation.

The diminution of the earth's gravitation to the sun when Jupiter is in conjunction, is about $\frac{1}{17000}$ of the whole gravitation.

In consequence of this change in the earth's gravitation to the sun, the line of the apsides of the earth's orbit changes its place in the heavens, sometimes advancing, and sometimes retreating; but, on the whole, advancing, because the earth's gravitation to the sun is more diminished than it is augmented.

In like manner, the aphelion of any inferior planet advances in consequence of the gravitation to the superior planets; but the aphelion of a superior planet retreats in consequence of the gravitation to the inferior planets. For these reasons, and because Jupiter and Saturn are much larger than the inferior planets, the aphelia of all the planets, excepting Saturn, advance, while the aphelion of Saturn retreats.

The accelerations and retardations of the planets Mercury, Venus, the Earth, and Mars, arising from their mutual gravitations, and their gravitations to Jupiter, nearly compensate each other; and no effects of them are perceived in any long tract of years. But the position of the aphelia of Jupiter and Saturn is such, that the retardations of Saturn sensibly exceed the accelerations; so that the anomalistic period of Saturn is increasing, at present, about a day in a century. On the contrary, the period of Jupiter is diminishing.

The disturbances occasioned by the mutual gravitations of the planets and comets are considerable. The comet of 1777 has suffered a remarkable change in its motions by the action of Jupiter.

The earth's motion round the sun is remarkably affected by the moon.

In consequence of the mutual gravitations of the planets, the nodes of a disturbed planet retreat on the orbit of the disturbing planet. Hence the nodes of all the planets retreat on the ecliptic, except that of Jupiter, which advances by retreating on the orbit of Saturn, from which it suffers the greatest disturbance.

OF THE APPROACH AND RECESS OF THE PLANETS TO AND FROM THE SUN IN EVERY REVOLUTION.

Having shewn you, that the forces which produce the regular motions of the planets vastly exceed those that disturb them, I shall explain more fully, how the motions in their orbits proceed from the actions of those powers; and how the planet is made to ascend and descend by turns, while it revolves about the center of its gravitation.

We have nothing similar to this in the motion of heavy bodies at the earth's surface; but you must remember, that the force, with which heavy bodies are projected from our most powerful engines, is inconsiderable, compared with the motions which their gravity could generate in them in a few minutes; and they move over such small spaces when compared with their distances from the center of the earth, that their gravity is considered as acting in parallel lines, without any sensible error; so that the centrifugal force arising from the rotation about that center, is altogether neglected.

But when the motion of a projectile in the larger spaces is examined, and traced in its orbit, it is necessary to take in the centrifugal force, arising from its motion of rotation about that center; and then it will appear, that there are indeed some laws of gravity, which would make the body approach to the center continually, till it fall into it, but that there are other laws which make bodies to approach, and suffer them to recede from it by turns.

If a planet at B, *plate* 15, *fig.* 6, gravitates, or is attracted towards the sun, so as to fall from B to y in the time that the projectile force would have carried it from B to X, it will describe the curve, BY, by the combined action of these two forces, in the same time that the projectile force singly would have carried it from B to X, or the gravitating power singly have caused it to descend from B to y; and these two forces being duly proportioned, and perpendicular to each other, the planet obeying both, will move in the circle B Y T.

But, if whilst the projectile force would carry the planet from B to b, the sun's attraction, which constitutes the planet's gravitation, should bring it down from B to 1, the gravitating power would then be too strong for the projectile force, and would cause the planet to describe the curve B C. When the planet comes to C, the gravitating power, which always increases as the square of the distance from the sun diminishes, will yet be stronger for the projectile force; and by conspiring in some degree therewith, will accelerate the planet's motion all the way from C to K; causing it to describe the arcs B C, C D, D E, E F, &c. all in equal times. Having its motion thus accelerated, it thereby gains so much centrifugal force, or tendency to fly off, at K in the line K k, as overcomes the sun's attraction; and the centrifugal force being too great to allow the planet to be brought nearer the sun, or even to move round him in the circle K l m n, &c. it goes off, and ascends in the curve K L M N, &c. its motion decreasing as gradually from K to B, as it increased from B to K; because the sun's attraction now acts against the planet's projectile motion, just as much as it acted with it before. When the planet has got round to B, its projectile force is as much diminished from its mean state about G or N, as it was augmented at K; and so, the sun's attraction being more than sufficient to keep the planet from going off at B, it describes the same orbit over again, by virtue of the same forces or powers.

A double projectile force will always ballance a quadruple power of gravity. Let the planet at B have twice as great an impulse from thence towards X, as it had before; that is, in the same length of time it was projected from B to b, as in the last example, let it now be projected from B to c; and it will require four times as much gravity to retain it in its orbit; that is, it must fall as far as from B to c: otherwise it could not describe B D, as is evident by the figure. But, in as much time as the planet moves from B to C in the higher parts of its orbit, it moves from I to K, or from K to L, in the lower part thereof; because, from the joint action of these two forces, it must always describe equal areas in equal times, throughout its annual course. These areas are represented by the triangles B S C, C S D, D S E, E S F, &c. whose contents are equal to one another, quite round the figure.

As the planets approach nearer the sun, and recede farther from him, in every revolution, there may be some difficulty in conceiving the reason why the power of gravity, when it once gets the better of the projectile force, does not bring the planets nearer and nearer the sun in every revolution, till they fall upon and unite with him; or why the projectile force, when it once gets the better of gravity, does not carry the planets farther and farther from the sun, till it removes them quite out of the sphere of his attraction, and causes them to go on in straight lines for ever afterward: but, by considering the effects of these powers, this difficulty will be removed. Suppose a planet at B to be carried by the projectile force as far as from B to b, in the time that gravity would have brought it down from B to 1; by these two forces it will describe the curve C; when the planet comes down to K, it will be but half as far from the sun, S, as it was at B; and therefore, by gravitating four times as strongly towards him, it would fall from K to Y in the same length of time that it would have fallen from B to 1 in the higher part of its orbit, that is, through four times as much space; but its projectile force is then so much increased at K, as would carry it from K to k in the same time; being double of what it was at B, and is, therefore, too strong for the gravitating power either to draw the planet to the sun, or cause it to go round him in the circle K l m n, &c. which would require its falling from K to W, through a greater space than gravity can draw it, whilst the projectile force is such as would carry it from K to k; and therefore the planet ascends in its orbit K L M N, decreasing in its velocity for the causes already assigned.

THE MOON'S IRREGULARITIES.

There is nothing that shews better the excellency of the Newtonian philosophy, or more clearly demonstrates the truth of its principles, than its so easily and clearly accounting for those many irregularities of motion, to which all the secondary planets, and the moon in particular, are subject.

Though these are called irregularities, yet they are not to be apprehended as random or fortuitous ones, but such as are regular under the like circumstances, and subject to numbers and calculation.

For it was by observing the period of these lunar inequalities, that Dr. *Halley* was enabled to foretel an eclipse of the sun, with an exactness little inferior to the observation itself.

It hath been seen before, that gravitation is a principle belonging to all gravitating matter; and that bodies, describing orbits about another placed in the center of their motion, by a centripetal and projectile force, describe equal areas in equal times.

As this is the law by which the primary planets regulate their motions about the sun, so likewise, was there no sun, by the same law would the moon regulate her motion about the earth.

This tendency of the moon towards the sun, then, is the cause of those inequalities in her motion, which are called her *irregularities*.

These are commonly reckoned eight, arising from causes now to be mentioned.

1. That variation, whereby, if we suppose E the earth, *plate* 15, *fig*. 7, and the circle, A B C D, the orbit of the moon, while the moon describes the quadrant A B, that is, while she goes from the quadrature to the conjunction, the force tending towards the sun at S, conspires with the force tending towards the earth at E, and therefore accelerates her motion. But while she goes from the conjunction B to the next quadrature, C, the force tending towards the sun will act contrary to the force tending towards the earth, and therefore will retard her motion.

In the same manner, while she goes from the quadrature C, to the next syzygy D, the same force tending towards S, will accelerate her again; but while she goes from thence to the quadrature at A, it will retard her again.

The moon, therefore, in her monthly revolution about the earth, is, by this action of the sun, alternately accelerated and retarded.

2. This force tending towards the sun being the *disturbing force*, or that force which prevents the moon from describing about the earth equal areas in equal times, will be greatest at the octants.

For, this force being resolved into two others, after Sir *Isaac Newton*'s manner, one of them at the quadratures or syzygies will be found to point from or towards E, the center of the earth directly, and therefore will not hinder the moon from describing equal areas in equal times; the other, likewise, in those places will be found to tend towards the center of the sun, and, therefore, neither of them will prevent the moon there from describing equal areas in equal times, *i. e.* will not at the quadratures disturb the moon's motion at all.

But, when the moon is in the octants, as at L, *plate* 15, *fig*. 8, this force being resolved into two others, one of them, as L H, will point directly to or from the center of the earth, and therefore will increase or diminish the moon's tendency towards the earth, but not hinder her from describing equal areas in equal times. But the other, as L I, or H G, points neither towards the center of the earth nor sun, and therefore, in the octants, prevents her describing equal areas in equal times.

But this being the mid-way between the quadrature and the syzygy, in both which places this disturbing force doth not prevent the moon from describing equal areas in equal times, it follows, that at the octants, this disturbing force will be the greatest of all.

And for this reason it hath always been found more difficult to obtain the moon's place in the octants agreeing with observation, than at the syzygies or quadratures.

3. The moon's orbit is more curved in the quadratures than in the syzygies.

For, her motion being accelerated during her progress from the quadratures to the syzygies, in the syzygies her motion will be quicker than it ought otherwise to be, and therefore her centripetal force less than it would otherwise be. She will, therefore, at the syzygies describe the portion of a larger curve, which, consequently, will be less curved than a smaller. That is, instead of describing the curve

A B, *plate* 15, *fig.* 9, or C D, she will describe the curve E F, or G K.

On the other hand, while the moon goes from the syzygies to the quadratures, her motion is continually retarded, and therefore, at the quadratures, her motion will be slower than it would otherwise be. At the quadratures, therefore, the moon will describe the portion of a lesser curve, which therefore will be more curved than a larger curve. That is, instead of describing the curve A B, or C D, she will describe the curve E F, or G K, *plate* 15, *fig.* 10.

Therefore, at the quadratures, the moon's orbit is more curved than at the syzygies.

4. Since these irregularities in the moon's motion proceed, as was said, from the action of the sun, it will follow, that where the action of the sun is greatest, the irregularities arising from it will be greatest also. But the nearer the earth is to the sun, the greater will be the action of the sun upon the moon; and, the more she tends towards the sun, the less will she tend towards the earth.

When, therefore, the earth is at the perihelion P, *plate* 15, *fig.* 11, and consequently at its least distance from the sun, the action of the sun upon the moon will be greatest, and destroy more of its tendency towards the earth than at any other distance, as S D, S C, S B, &c.

Therefore, when the earth is at the perihelion P, the moon will describe a greater orbit about the earth, than when the earth is at any other distance from the sun, and consequently then her periodical time will be the longest.

But the earth is at its perihelion in the winter, and, consequently, then the moon will describe the outermost circle about the earth, and her periodical time will be the longest. And this agrees with observation.

For the same reason, when the earth is at its aphelion A, the tendency of the moon towards the earth will be the greatest, and consequently her periodical time the least. And in this case, which will be in the summer, she will describe the innermost circle about the earth.

5. Since the moon, from what has been said, appears to describe an elliptical orbit about the earth E, *plate* 15, *fig.* 12, in the focus of it; and since her centripetal force towards the earth, by means of the action of the sun, is continually increasing or decreasing, but not equably, that is, sometimes less, and sometimes more, than in the inverse duplicate proportion of the distance of the moon from the earth; therefore, in this case, the line of the moon's apsides, A B, will be continually going backwards or forwards. That is, the axis, A B, will not always lie in that situation, but go backwards into the situation K L, or forwards into the situation F G.

Since however, taking one whole revolution of the moon about the earth, the action of the sun more diminishes the tendency of the moon towards the earth, than it augments it, therefore the motion of the apsides forwards exceeds their motion backwards. Upon the whole, therefore, the apsides of the moon's orbit go forwards, or according to the order of the signs.

6. Because the moon describes an eccentrical orbit about the earth at E, *plate* 15, *fig.* 13, and the action of the sun upon her sometimes increases her tendency towards the earth, and sometimes diminishes it, *i. e.* makes her gravity towards the earth increase or decrease too fast. If, while the moon ascends from her lower apside, A, her gravity towards the earth decreaseth too fast, instead of describing her semi-ellipsis A B C, and coming to the higher apside at C, as she would otherwise do, she

will run out in the curve B F D, and come to the higher apside at F. But the curve, A B F D, is more eccentric than the curve A B C D.

Therefore, when the gravity of the moon towards the earth decreases too fast, the eccentricity of her orbit will increase.

On the other hand, if the moon is going from her higher apside C, *plate* 15, *fig*. 14, to her lower, A, and her gravity towards the earth increases too fast, instead of describing the same ellipsis C D A, and so coming to the lower apside at A, she will approach nearer to the earth, and describe the curve D F B, and so come to the lower apside at F. But the curve, C D F B, will be less eccentric that the curve D A B C.

Therefore, when the gravity of the moon towards the earth increases too fast, the eccentricity of her orbit will decrease, and the orbit itself will approach nearer to a circle.

Therefore, the eccentricity of the moon's orbit will be continually varying.

7. In considering the irregularities of the moon's motion, we have hitherto supposed the plane of her orbit as coinciding with the plane of the ecliptic, because her motion would be affected with the irregularities hitherto spoken of, if in reality it did so.

But it hath been before observed, that one half of the moon's orbit A C B, *plate* 15, *fig*. 15, is raised above the plane of the ecliptic A E B G, and the other half, A D B, depressed below it; and the points A, B, where the moon's orbit crosseth the plane of the ecliptic, are called the *nodes*, and the line A B, joining these points, is called the *line* of the nodes.

But when this line of the nodes, A B, lies in conjunction with the sun, S, it is at rest; but in all other positions it goes backwards.

When this line of the nodes, A B, lies in the quadrature, *plate* 15, *fig*. 16, with the sun S, it goes backwards fastest of all.

8. It has been formerly observed, that the orbit of the moon is inclined to the plane of the ecliptic in a certain angle; but this angle is not constantly the same, but sometimes greater and sometimes less, depending upon the different position of the line of the moon's nodes with respect to the sun.

When the line of the nodes, A B, *plate* 15, *fig*. 17, passes through the syzygies, the plane of the moon's orbit produced passes through the center of the sun S, and, consequently, not being affected by the action of the sun, is then at its greatest state, making an angle with the ecliptic of about 5 degrees 18 minutes.

When the line of the moon's nodes, A B, *plate* 15, *fig*. 18, lies in a quadrature with the sun S, then, supposing the line, A B C D, to represent the plane of the ecliptic, and A E B F the orbit of the moon, let the moon be supposed to have just now passed the ascending node at A, and going to her conjunction with the sun at E.

The moon will then be going farther and farther from the plane of the ecliptic A B C D, and, was there no action of the sun, would come in conjunction with him at E.

But, because of the action of the sun, the moon, in going from the quadrature at A, towards her conjunction, will be perpetually drawn down towards the ecliptic, and therefore will not come to a conjuction of the sun at E, but at G, making an angle with the ecliptic, G A C, less than E A C.

But the sun continuing still to act, after the moon has arrived at her conjunction, will go on to draw her down towards the ecliptic; by which means she will not cross the ecliptic at the point B, her former node, but in some other point nearer to the sun, as K.

But wherever the moon crosses the ecliptic, is her node. Therefore, her node in the mean time hath gone backward from B to K, *plate* 15, *fig.* 19, and the moon hath described a semi-orbit A G K, making a less angle with the ecliptic, than the orbit A E B, which she would have described had there been no action of the sun at all.

CONCLUSION.

Aristotle concludes his treatise, De Mundo, with observing, that "to treat of the world without saying any thing of its author would be impious," as there is nothing we meet with more frequently and constantly in nature, than the traces of an all governing Deity.

The philosopher who neglects these traces, and contents himself with the appearances only of the material universe, and the mechanical laws of motion, neglects what is most excellent; and prefers what is imperfect to what is supremely perfect, finitude to infinity, what is narrow and weak to what is unlimited and almighty, and what is perishing to what endures for ever. Those who do not attend to the manifest indications of supreme wisdom and goodness perpetually appearing before them, wherever they turn their views or inquiries, too much resemble those ancient philosophers, who made night, matter, and chaos, the original of all things.

The plain argument for the existence of the Deity, obvious to all, and carrying with it irresistible conviction, is from the evident contrivance and fitness of things for one another, which we meet with throughout all parts of the universe. There is no need of nice or subtile reasonings in this matter; a manifest contrivance immediately suggests a contriver. It strikes us like a sensation; artful reasonings against it may puzzle us, but it is without shaking our belief.

No person, for instance, that knows the principle of optics, and the structure of the eye, can believe that it was formed without skill in that science; or that the ear was formed without the knowledge of sounds; or that male and female in animals were not formed for each other, and for continuing the species. All our accounts of nature are replete with instances of this kind.

The admirable and beautiful structure of things for final causes, exalts our idea of the contriver; the unity of the design shews him to be *one*; revelation, that this one is Jesus Christ. The great motions in the system performed with the same facility as the least, suggest his almighty power, which gave motion to the earth and the celestial bodies, with equal ease as to the minutest particles. The subtilety of the motions and actions in the internal parts of bodies, shews that his influence penetrates the inmost recesses of things, and is every where exerted. The simplicity of the laws that prevail in the universe, the excellent disposition of things, in order to obtain the best ends, and the beauty which adorns the works of nature, far superior to any thing in art, suggest his consummate wisdom. The usefulness of the whole scheme, so well contrived for the intelligent beings that enjoy it, with the internal dispositions and moral structure in those beings themselves, shew his unbounded goodness.

These are arguments which are sufficiently open to the views and capacities of the unlearned, while at the same time they acquire new strength and lustre from the discoveries of the learned. God acting and interposing in the universe, shews that he governed it, as well as that he formed it; and the depth of his counsels, even in conducting the material universe, of which a great part surpasses our knowledge, keeps up an inward veneration and awe of this great Being, and disposes us to receive what may be otherwise revealed to us concerning him.

It has been justly observed, that some of the laws of nature now known to us, must have escaped us if we had wanted the sense of sight. God can bestow upon us other senses of which we have at present no idea, without which it may be impossible for us to know all his works, or to have more adequate ideas of his nature. In our present state, we know enough to be convinced of our dependency on him, and of the duty we owe to him as the Lord and Disposer of all things.

Though the power of God is manifested in all his works, it is in the heavens that it still seems to beam forth in its greatest lustre. By his power acting there, he directs the courses of the planets, determines the circumstances of their motions, and fixes the times of their revolutions. As a General at the head of an army, HE gives the signal to the heavenly bodies, and immediately they shoot forth, and proceed in their proper orbits. It is in consequence of the laws laid down by HIM, that the moon goes round the earth in a month. It is HE that has combined the two motions of the earth, one by which we obtain the vicissitudes of day and night; the other, by which the seasons of the year are brought about. HE it is, who at the appointed times sends salutary winds, and fruitful rains and dews; who gathers together the waters in their sources, and causes them to flow from thence in the beds of rivers to their great receptacle, the sea. It is HE who makes the buds to open, the fruits to ripen, and animals to be prolific, ordering all things according to their different nature, regulating their birth, their growth, and their dissolution.

Though the Author of so many wonders be invisible, you cannot on that account deny his power, or doubt his existence. You cannot see your soul, yet the effects it produces in you and around you, are sensible proofs of its existence. It is the same with many of the operations in nature. In like manner, God also, though invisible in himself, is visible in all his works, and in them appears equally strong in power, admirable in wisdom, eternal in duration, and supreme in perfection.

The whole universe conspires to celebrate his praise, from whom it derives all its majesty and beauty. The sun that shines in brightness declares the ineffable splendor of its Almighty Creator. The moon and stars proclaim to an understanding heart the adorable power of the hand that guides them. The earth, so richly stocked with productions of higher and lower rank, with the various kinds of vegetable and animal life, paint in the strongest terms the riches of the divine nature, from whom issues all that adorns the earth, improves the mind, and delights the senses; governing all things with infinite wisdom, goodness unlimited, power uncontrouled.

That a Divine Mind presides over and governs the universe, is indeed the natural conclusion drawn by common reason from the evidence of common sense. For, who that sees this universal frame thus wondrous fair, but must infer the cause of it to be full of wondrous beauty? Who, that observes ever so slightly that constancy which is in the motions of the planets, and in the risings and settings of the fixed stars, &c. can possibly imagine the inconstancy of chance to be the mover? What man, not disordered in his own mind, can suppose any other thing than mind to be the cause of that everlasting order, which appears in the regular interchanges of the elements, and the circling returns of the successive seasons.

As far as I have conducted you through various branches of natural philosophy; as far as I have proceeded in giving you a general view of the system of the world, beauty has every where struck your eye, and engaged you to proceed and scrutinize further the operations in nature. The more accurate your scrutiny, the more you will discover of regularity, symmetry, and order, in the constitution of nature's frame; the further you penetrate into her deep recesses, dividing and subdividing, opening and unfolding, the minutest part of every visible form, the still more you will find of beauty within beauty, and find every order to contain a variety of other orders.

LECTURE XLVI.

ON ELECTRICITY.

Mr. Stillingfleet has well observed, that if the whole scene of nature were laid open to our view, were we permitted to behold the connexions and dependencies of every thing on every other, and to trace the economy of nature through the smaller, as well as the greater parts of this globe, we should probably find, that the Great Architect had contrived his works in such a manner, that we cannot properly be said to be unconcerned in any one of them; and therefore, those studies, which seem upon a slight view to be quite useless, may in the end appear of no small importance to mankind.

If you look back into the history of arts and sciences, you will be convinced, that men are apt to judge too hastily of things of this nature; you will there find, that he who gave curiosity to his creature, man, gave it for good and great purposes; and that he rewards with useful discoveries what in the first instance are condemned as trifling or minute researches.

But it is true, that these discoveries are not always made by the searcher, or his cotemporaries, or sometimes even by the immediate succeeding generation; but there can be no doubt, but that advantages of one kind or other always accrue to mankind from an investigation of the operations in nature. Some men are born to observe and record what perhaps by itself is perfectly useless, but yet of great importance to another, who follows and goes a step further, still as useless to him; another succeeds; and thus by degrees, till at last one of superior genius comes, who, laying all that has been done before his time together, brings on a new face of things, improves, adorns, and exalts human society.

All those speculations concerning lines and numbers so ardently pursued, so exquisitely conducted by the Grecians, what did they aim at; what did they produce for ages? A little arithmetic, and the first elements of geometry, were all they had need of. This *Plato* asserts; and though, as being himself an able mathematician, and remarkably fond of those sciences, he recommends the study of them, yet he makes use of motives that have no relation to the common purposes of life.

When *Kepler*, from a blind and strong impulse, merely to find analogies in nature, discovered that famous law between the distance of the several planets from the sun, and the periods in which they complete their revolutions, of what importance was it to him or to the world?

Again, when *Galileo*, pushed on by the same irresistible curiosity, found out the law by which bodies fall to the earth, did he, or could he foresee, that any good could come from his ingenious theorems; or was there any immediate use made of them?

Yet, had not the Greeks pushed their abstract speculations so far; had not *Kepler* and *Galileo* made the above-mentioned discoveries, we never could have seen the greatest work that ever came from the hands of man, Sir *Isaac Newton*'s Principia.

Some obscure person, whose name is not so much as known, diverting himself idly, as a stander by would have thought, with trying experiments on a seemingly contemptible piece of stone, found out a guide for mariners on the ocean; and such a guide, as no science, however subtile and sublime its speculations may be, however wonderful its conclusions, could ever have attained. It is the same with *electricity*. Who could have supposed, on seeing a person amusing himself with the effect of excited amber on light bodies, that this was one of the first links in a science that should teach men how to disarm the clouds of lightning, divest the storm of its terrors, and give life and power to the animal frame.

Other instances might be produced to prove, that bare curiosity, in one age, is the source of the greatest utility in another; and what has been frequently said of the chemists, may, perhaps, be applied to every other kind of virtuosi. They hunt, perhaps, after chimeras and impossibilites, and find something really valuable by the bye. We are but instruments under the Supreme Director, and do not know, in many cases, what is of most importance for us to search after; but we may be sure of one thing, that if we study and follow nature, whatever paths we are led into, we shall at last arrive at something valuable to ourselves and others, but of what kind, we must be content to be ignorant.

The nature of aqueous vapours, of fire, and the electrical fluid, will clearly prove to you, that a number of substances may act in nature without being known to us; and that it is our ignorance of their existence, which envelopes in obscurity so many phenomena.

If it were not for the visible diminution of water when its surface is exposed, and for the hygroscopical appearances, we should not have known that aqueous vapours existed in the atmosphere. Notwithstanding all these phenomena, there are still those who do not admit their existence. It is not difficult, however, to shew, that the effects produced by this fluid, while in an imperceptible state, are incomparably greater than the immediate symptoms of its existence.

Again, without heat, an effect which is only produced by fire when it is disengaged or free, we should have been ignorant of the existence of fire: yet how great and various are the effects it produces in the combined or latent state! Heat is a symptom of the presence of this fluid, and of its degree of density, when free and disengaged; but if you seek to follow it in the phenomena of nature, you find, that when it escapes from observation, it is acting the most important of parts. It is the same with light, the companion of fire. If it were not for the impression it makes upon our eyes, we should be ignorant of the greatest and most immediate agent of all terrestrial phenomena.

Thus you see, that there are substances of the greatest importance for modifying those which are more grossly perceptible, and of which, in the mean time, we have little or no knowledge, though they are producing the greatest effects.

But still further, the motions of light occasioned by the electrical fluid, when its natural equilibrium is disturbed, are the only signs which give us notice of its existence. All electrical phenomena concur in proving the existence of a certain fluid, possessed of certain characters, capable of particular modifications, and disseminated over the whole surface of the globe; the why or wherefore is still unknown, we are still ignorant of its functions. But we are at the same time ignorant of the cause of so many phenomena in nature, that we ought not to despair of being able to discover those with which it is connected, and how it influences them by its composition and decomposition.

It results from the observations I have now made, that the known expansible fluids have two kinds of properties; one whereby they manifest themselves to one or more of our senses, the other by which they act imperceptibly in a number of phenomena. It is not then necessary, as a proof of the existence of a substance, nor of its being a principal agent in phenomena, that it should be manifested to our senses. But it is essential in nature, as soon as you consider physical objects, that to every phenomenon there be a cause; and the only method of assigning a reasonable one, where they are not immediately discoverable, is analogy. When therefore certain phenomena, whose cause is hidden, are analogous to other phenomena that we attribute to the intervention of some substance, we are naturally led to some substance as a cause of the first mentioned phenomena; and nothing will oppose their admission, if they explain what cannot be explained without, and if there is nothing which renders the existence of the substance obscure.

Here I cannot refrain from observing, that the French philosophers, after extending the influence of electricity over all nature, now pass it by as if unworthy of notice; its name is not even to be found *dans le tableau de la novelle nomenclature.*

Philosophy owes much to the assistance it has received from mathematicians; but this only happens when they apply themselves to the study of phenomena; when neglecting these, calculations are made to serve an hypothesis; the more elegant and beautiful they are, the more detrimental they become to science. It is thus, that *Æpinus*, by a mathematical theory of electricity, has closed the door on all our reserches into the nature and operations of this fluid.

ELECTRICAL APPEARANCES.

From these preliminary observations, which I considered as necessary to excite your attention to the electric fluid, and to lead you to look out for, and to trace its connexion with other agents in nature; I shall proceed to point out some of the most striking electrical appearances. The knowledge obtained of electricity, like most other articles of science, has arisen from very small beginnings, and by very slow degrees to its present height. It had been known for ages, that amber, jett, and other bodies, would, upon rubbing, attract and repel light bodies, as hairs, feathers, down, dust, &c. and as this property was most conspicuous in amber, which in the Greek is called *electron*, the peculiar power of that body was termed *electricity*. Upon further inquiry, it was found, that not amber only, but several other substances had the same properties in a high degree; that glass, resinous substances, silk, dry wood, &c. have the same properties; and that any of these when dry, and rubbed for a short time, would attract light substances.

I rub this stick of sealing-wax with soft flannel, and you see it attracts any light substances, as hairs, feathers, &c. that I bring under it; rub a dry glass tube with dry silk, and you will find it produce the same effect. Let us now darken the room, rub the glass tube again, and you will see sparks of fire follow your hand; present your knuckle to the tube, and these sparks will be formed into pencils or brushes of light, attended with a crackling noise like that of a green leaf in the fire.

The friction has, in these instances, manifested to the senses the existence of a substance that was before imperceptible. The body that is made by friction to exhibit these appearances, is said to be *excited*. The appearances are termed *signs of electricity*.

Here is a fine downy feather tied to a silk string; I electrify it strongly by touching it with the excited glass tube, and it immediately flies from, or is repelled by the glass tube. I now present an excited stick of sealing-wax, and the feather immediately flies towards it. Thus you see, that what is attracted by excited wax, is repelled by excited glass. This experiment gave rise to a very important distinction in electricity, implying a contrariety of agency therein, and one power or agent by the glass was denominated *vitreous*, the other *resinous* electricity.* Further discoveries shewed, that glass or wax would, according to the circumstances in which they were situated, produce either power.

Our two next experiments lead us also to another very important distinction in this branch of science. I suspend a brass ball by a wire from the end of the glass tube opposite to my hand, and excite the tube as before; as soon as the tube is excited, you will find, that the ball has acquired all the electric properties of the tube; it will, like it, attract light bodies, and give the spark. Let us now suspend the ball by a silk string, and excite the tube as before; you may now rub as long as you please, but the ball will exhibit no signs of electricity. Here then we have two substances, through one of which, the wire, the electric properties may be conveyed; whereas the other, that is, the silk, prevents their passing to the ball. The wire is therefore called a *conductor* of electricity. The silk is termed a *non-conductor*.

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* Now generally called by electricians *positive* and *negative electricity*. EDIT.

Or, in more general terms, all those bodies, through which the electrical fluid is transmitted freely, are termed *conductors*. Those bodies, through which it does not pass so freely, are called *non-conductors*.

A body resting entirely upon non-conductors is said to be *insulated*. Thus, in the last experiment, the ball was insulated, because it was suspended by a silk string, which is a non-conductor. Insulation prevents the dissipation of the electrical appearances.

THE PRINCIPLES OF ELECTRICITY DEDUCED FROM EXPERIMENTS ON ATTRACTION AND REPULSION.

I have already shewn you, that a light body electrified by excited glass, is *repelled* thereby, but will be *attracted* by excited wax; and that, on the other hand, if it be electrified by excited wax, it will be repelled thereby, but will be attracted by excited glass. This observation you must keep in mind, without it you can never understand the operations of electricity. The greater part of the experiments in this science, and the whole of the reasoning thereon, depend on a reference to these facts.

For the following experiments, I make use of small light balls formed out of the pith of elder; they are suspended by fine linen threads from small cylinders of wood, and are insulated upon a common wine glass, that is dry, free from dust, fibres of down, &c.

I electrify two balls, thus suspended by excited glass, and you see they repel each other. I destroy this electricity by touching them with my hand. I again electrify them, but with excited wax, and they again repel each other. I bring the balls electrified by wax towards those electrified by glass, and they immediately fly towards each other.

From these experiments you will infer, 1. That bodies electrified vitreously repel each other. 2. That bodies electrified resinously repel each other. 3. That bodies electrified with contrary powers attract each other.

As those light substances which possess the same electric power repel each other, it will always be easy for you to discover with what power they are electrified. If they are repelled by excited glass, they possess the vitreous electricity; if they are attracted thereby, they are resinously electrified; on the contrary, those attracted by excited wax, are vitreously, and those repelled thereby, resinously electrified. In ascertaining the nature of the electric power, you must avoid bringing the bodies to be tried near each other suddenly; or one strongly electrified too near one that is weakly, so as it may render the experiment doubtful, for reasons that will soon be apparent.

Before I go any further, it may be proper to point out to you the leading features of that theory of electricity, Mr. *Eeles*'s,* which I adopt in these

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* See *Eeles*'s Philosophical Essays in several letters to the Royal Society, London, 1771. On a comparison of this work with the greater part of the modern writers on electricity, you will find, that they have been gradually giving up the most essential distinctions of the Franklinian theory, and adopting those of Mr. *Eeles*. See *Wilson, Henly, Gray, Milner, Brooke, Peart, Read*, &c. &c. And you will find him laying down principles, and making expe-

Lectures. I consider, with him, all those electrical operations that are manifested to the senses, as occasioned by two distinct, positive, and active powers, which equally and strongly attract and condense each other; but when by any circumstance they are rendered unequal to each other, the increased power expands into an atmosphere.

These two powers exist together in all bodies; in their natural state they are always conjoined; the electric signs, or what we call electricity, are only rendered sensible to us by the separation of these powers. In other words, though the electric matter is acting the most important part among the operations in nature, in its united, and to us, latent and invisible state, yet it becomes no object to our senses, till its powers are separated and rendered unequal.

When the powers are separated and brought into action, the increased power expands, and forms what may be termed an electrical atmosphere. If any body be immerged in this atmosphere, the powers thereof are separated, and that which is of the same kind with the atmosphere is repelled, while the contrary power is attracted: as long as the body remains immerged therein, the powers remain separated. It is however to be observed, that in exciting electrics, the powers are never entirely separated. The diminished power acts inward to the electric, while the increased power acts outward with an extensive atmosphere.

I hold an excited glass tube over this metallic cylinder, placed on a dry wine glass, as an insulating stand, *plate* 1, *fig.* 1, *(Electricity)*, but at a certain distance from it, which distance will depend upon

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riments, that have within a few years been brought forwards as new; some have indeed been rejected at first, because deemed contradictory to a favourite theory, but which have since been fully acknowledged.

the power of the glass; it repels the vitreous electricity of the tube into the balls, which will diverge with vitreous electricity, and will of course recede from excited glass. I remove the excited glass from over the balls, and they close. A temporary separation of the electric matter inherent in the cylinder, is in this instance produced by the influence of the excited glass; as soon as this influence is removed, the powers unite, and the balls close.

I now place two cylinders, with their ends in contact with each other, *plate* 1, *fig*. 2, and hold the excited tube over the end A; each pair of balls diverge. While they are in this state, separate them one from the other, and you will find the balls of A to be vitreously electrified, and these of B resinously so; proving, that while the body remained immerged in the atmosphere, the electric powers thereof were separated, one being at each end. Bring the tubes together again, and the balls immediately close; proving, 1. That the separated powers attract each other. 2. That when united, they condense each other, and that all electric signs are immediately lost. 3. The co-existence of the two powers in the cylinders.

Again electrify the balls equally, but with the same powers, then bring the ends of the cylinders together, and the divergence of the balls will not be altered; which shews, that equal atmospheres of the same kind do not act on each other.

Hold an excited glass tube over the cylinder, *plate* 1, *fig*. 4, and at the same time keep one of your fingers in contact with the opposite end of the cylinder, remove the glass tube and finger together, and the balls will diverge with resinous electricity; for, on trying, you will find them fly towards excited wax, and recede from excited glass. The vitreous power is repelled by the excited tube, and passes into the finger, which, in exchange, communicates resinous electricity to the cylinder.

The tendency of an electric atmosphere to produce the contrary electricity, in the bodies contiguous to it, is pleasingly illustrated by the following experiment. In this, there are four cylinders, A, B, C, D, *plate* 1, *fig.* 3; excited glass held over A, repels the vitreous power into B, and draws the resinous into A; in the same manner, B repels the vitreous power of C into D, and draws the resinous into C; separate B and D from A and C, just before the excited glass is removed, and you will find A and C possessing the resinous, B and D the vitreous electricity; as you will find, by bringing the excited glass towards the balls, those at A and C will move towards the glass, those at B and D will recede from it.

You saw in a former experiment, where the balls were equally electrified with contrary powers, that on bringing the cylinders together, the powers united, and all electrical signs vanished. But if one be electrified more than the other, that which is least so, loses all its electricity after contact, and the two remain electrified, with the excess of the electricity of that which was strongest.

From these experiments it appears, that the increased power expands itself, and acts outwards, and that in proportion to the subtraction of the other power; and that this is the sphere of the expanded power, which is called an electric atmosphere.

It appears further, that no substance seems to be electrified, while the powers are equal in or on that body; but in proportion as there is a greater quantity of one power, than there is of the other, then the increased power acts outwards from that body, and the body will be electrified with that power, and will repel any other body electrified with the same power; but will attract any substance electrified with the contrary power; and after contact between them, all electrical signs vanish, if they were equally electrified; but if unequally, both will remain electrified with the excess of the strongest power.

These positions will be confirmed by other experiments, in which you will see the contrary directions of the two powers.

OF THE ELECTRICAL MACHINE, *plate* 1, *fig.* 5, AND ITS MODE OF ACTION.

By turning the handle of the machine, and of course the glass cylinder which moves with it, electricity is produced; and this we shall find, as before, of two kinds, each strongly attractive of the other, though repulsive of a similar kind; when united, the expansive power they before exerted, is condensed, and all electric signs vanish.

To render these positions clear, I insert a wire, B, in the cushion, and another, C, in the conductor; each of these is furnished with a brass ball at top, and each of them has a sliding wire with balls on its end, that it may be set at any convenient distance from the other. On turning the cylinder, you observe, 1. That I can obtain an electric spark from the balls of either wire on presenting my knuckle thereto. 2. That a strong spark will pass from one ball to the other. 3. That on holding a cork ball suspended by silk, between the two brass balls, it is alternately attracted and repelled from one to the other. 4. Electrify a pair of insulated pith or cork balls by the cushion, and you will find them to possess the resinous electricity; electrify them by the conductor, and they will possess the vitreous power.

5. Join the balls together, and all electrical signs vanish.

On the other hand, if you place both wires either on the conductor, or the cushion, you will find, that no spark will pass between them, that the cork ball remains stationary, being neither attracted nor repelled by the balls, and this because they both possess the same kind of electricity.

From these experiments we infer, that the conductor and the cushion are electrified with different powers; that one attracts what the other repels, and that when they are united, they exhibit no signs of electricity: that on the separation of the powers by excitation, one power attaches itself to the excited electric, the other to the rubber.

The whole variety of electrical experiments appear to be nothing more than different modes of destroying or restoring an equilibrium. By destroying the equilibrium, two positive powers are at the same time produced. By restoring the equilibrium, all things return to their natural state, and every appearance of electricity ceases. The two powers are so connected, that one can never be exhibited without producing the other. It is probable, that in the general operations of nature, this fluid always acts in its united form, that in which it is to our senses latent and invisible.

On turning the cylinder and separating it from the silk, the electric powers are separated, the cylinder gives its resinous power to the cushion in exchange for the vitreous; the conductor in like manner exchanges its powers with the cylinder; for, as long as the cushion communicates with the table by a chain, and you continue turning the cylinder, you will find the conductor strongly electrified with the vitreous power. Take the chain from the cushion, and suspend it from the conductor; on turning the cylinder you will find the cushion strongly electrified with the resinous power. Connect the cushion and conductor by a chain, and the powers re-unite almost as soon as they are separated, and the electrical signs disappear.

We now see, why conducting substances cannot be electrified unless they are insulated. It is because the two powers join instantaneously in the non-conductor, and can therefore exert no sensible action.

When I turn the cylinder slowly, only a small quantity of the fluid is excited, and it does not fly far in the form of a spark; but when I turn somewhat faster, and make the black silk adhere to the glass, the quantity of excited electricity is considerably increased. The flash or spark passes through a greater space, and assumes a crooked or zig-zag direction, resembling the flashes of lightning. The brilliancy of the spark depends much on the pressure of the atmosphere; for the spark which explodes in air is vivid like lightning; but if the same be tried in an exhausted receiver, instead of a spark and explosion, you have only a silent, faint, diluted stream.

Before I proceed to other experiments, I shall explain your machine more fully, and shew you how to excite it powerfully. The parts of the machine, which fall more immediately under your attention, are, 1. The electric, or the glass cylinder which is to be excited. 2. The mechanical contrivances by which it is put in motion. 3. The cushion and its appendages. 4. The conductor, or conductors.

The glass cylinder of the machine before you, *plate* 1, *fig*. 5, is put in motion by a simple winch A. This is less liable to be out of order, than those that are turned with a multiplying wheel and pulley, and will also enable you to excite the machine more powerfully.* The cylinder, F G I K, is supported by two strong perpendicular pieces D E. The axis of one cap of the cylinder moves in a small hole at the upper part of one of the supports. The opposite axis passes through the upper part of the other support. To this axis the winch or handle is fitted. The cushion is supported and insulated by a glass pillar; the lower part of this pillar is fitted into a wooden socket, to which a regulating screw, H, is adapted, to increase or diminish the pressure of the cushion against the cylinder. A piece of silk comes from the under edge of the cushion, and lies on the cylinder, passing between it and the cushion, and proceeding till it nearly meets the collecting points of the conductor. The more strongly this silk is made to adhere to the cylinder, the stronger is the degree of excitation. Before the cylinder, or opposite to the cushion, is a metallic tube Y Z, supported by a glass pillar L M, with a set of points in the front, called the *collector*, to collect the electricity from the cylinder. This tube is sometimes called the *prime conductor*, often only the *conductor*.† For the more conveniently trying experiments on the two powers, and exhibiting the different states of the cushion and conductor, there are two wires, B, C, to be fixed occasionally, the one to the conductor, the other to the cushion; on the upper part of these, are balls furnished with sliding wires, that they may be set at various distances from each other.

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* There are some instances in which, I think, a multiplying wheel and pulley are preferable. They are less awkward and tiresome to beginners than an handle. I think those machines the most complete, which are capable of being used occasionally either way. EDIT.

† The conductor exhibited in the figure is of the T shape, which is a convenient, but not an essential form; they are more frequently made cylindrical, with the collecting points placed on the side. EDIT.

Before the electrical machine is put in motion, examine those parts which are liable to wear either from the friction of one surface against another, or to be injured by the dirt, that may insinuate itself between the rubbing surfaces. If any grating or disagreeable noise is heard, the place from whence it proceeds must be discovered, wiped clean, and rubbed over with a small quantity of tallow; a little sweet oil or tallow should also be occasionally applied to the axis of the cylinder.

The screws that belong to the frame should be examined, and if they are loose, they should be tightened.

The different working parts of the machine having been looked into, and put in order, the glass cylinder, and the pillars which support the cushion and conductor, should be carefully wiped with a dry old silk handkerchief, to free them from the moisture which glass attracts from the air, being particularly attentive to leave no moisture on the ends of the cylinder, as any damp on these parts carries off the electric fluid, and lessens the force of the machine: in damp weather it will be proper to dry the whole machine, by placing it before, but also at some distance from, the fire.

Take care that no dust, loose threads, or filaments, adhere to the cylinder, its frame, the conductors, or their insulating pillars; because these will gradually dissipate the electric fluid, and prevent the machine from acting powerfully.

Rub the glass cylinder first with a clean, coarse, dry, warm cloth, or a piece of wash leather, and then with a piece of dry, warm, soft silk; do the same to all the glass insulating pillars of the machine and apparatus; these glass pillars that are varnished must be rubbed more lightly than the cylinder.

A hot iron may, in some cases, be placed on the foot of the conductor, to evaporate the moisture, which would otherwise injure the experiments.

To excite your machine, clean the cylinder and wipe the silk.

Grease the cylinder by turning it against a greasy leather, till it is uniformly obscured. The tallow of a candle may be used.

Turn the cylinder till the silk flap has wiped off so much of the grease, as to render it semi-transparent.

Put some amalgam on a piece of leather, and spread it well, so that it may be uniformly bright; apply this against the turning cylinder; the friction will immediately increase, and the leather must not be removed until it ceases to become greater.

Remove the leather, and the action of the machine will be very strong.

The pressure of the cushion cannot be too small, when the excitation is properly made.

The amalgam is that of Dr. *Higgins*, composed of zinc and mercury; if a little mercury be added to melted zinc, it renders it easily pulverable, and more mercury may be added to the powder, to make a very soft amalgam. It is apt to crystallize by repose, which seems in some measure to be prevented by triturating it with a small proportion of grease: and it is always of advantage to triturate it before using.

A very strong excitation may be produced by applying the amalgamed leather to a clean cylinder, with a clean silk; but it soon goes off, and is not so strong as the foregoing, which lasts several days.*

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* In summer, a machine and apparatus, kept in a room free from dust, will require merely wiping with a dry cloth. In winter, and if the apparatus be damp and foul, carefully wiping it all over, and a general small degree of warming by the fire, will be necessary. Supposing the silk used clean and perfect, a small application of amalgam to the cylinder or rubber will occasion the cylinder to be strongly excited. Streams of fire, or a crackling noise at the knuckle, when presented to the cylinder, will be a sure proof of the machine being in the best order. EDIT.

OF THE MOMENTUM OF THE ELECTRICAL FLUID.

The great strength and velocity displayed by the electrical fluid in its motions, is an object well worthy your investigation: and if it be granted (and I think I shall be able to prove it to you) that the electric matter is the same with the solar fluid, then will the ultimate cause of its momentum be the power by which the light of the sun is propagated, the pressure of which being equal all round upon all bodies, it can neither move them one way nor the other. But if, by means of any other power, this pressure is lessened upon any particular part, the current of matter will set forwards towards that place, with a force proportioned to the diminution of the pressure. Thus, in the common experiments of the air-pump, when the air is exhausted from the receiver, the pressure of the superincumbent atmosphere is directed towards every part of the glass; so that if it be of a flat square shape, and not very strong, it will certainly be broken. Now, there is reason to suppose, that after the air is exhausted from the receiver, it is full of another subtile fluid of the same nature with the electric. If this could also be extracted from the receiver, the pressure on its sides would be much greater, because not only the atmosphere, but the whole surrounding ether, would urge towards that place; and it is not probable, that this pressure could be resisted by any force whatsoever.

The momentum, therefore, of the electrical fluid depends on two causes; the pressure of the atmosphere upon the electric matter, and the pressure of one part of this matter upon another, which is extended throughout the immensity of space. The force and velocity of the fluid depends therefore, in a great measure, on that which surrounds us. There is a certain state of this fluid, that we violate by our experiments; when this violation is small, the powers of nature operate gently in restoring the disorder we have introduced; but, when any considerable deviation is occasioned, the same powers restore the original constitution with extreme violence.

EXPERIMENTS ON ELECTRICAL ATTRACTION AND REPULSION.

To the top of this wire, three large downy feathers are affixed by three linen threads. I insert the lower end of the wire into the prime conductor; upon turning the cylinder, the plumage expands every way, the threads also recede as far as possible from each other. If I place my finger near the feathers, all the plumulæ bend towards it; if I move my finger this way or that, they all move after it as if alive; I put my hand on the conductor, immediately the threads lose their divergence, the plumulæ collapse, and fall close together; I take my hand away, the threads diverge, and the feathers expand as before.

I cannot explain to you the mechanism which occasions the threads to diverge; but I can state those facts which must concur to occasion it. We know that those light bodies, which possess the same kind of electricity, separate from, or repel each other; the finger communicates to them the contrary power; towards this, therefore, they are impelled by their nature, in order to restore an equilibrium which our operations have destroyed. By putting my hand on the conductor, the powers are immediately exchanged and united, and the electrical effects cease.

I place this cork ball, suspended by silk, so that it may be even with the conductor, and at about six inches from it. I turn the machine, but the cork remains quiet; touch it with the end of the wire in your hand, and the vitreous power of the ball is driven into you, and an equal quantity of the resinous is communicated to the ball, which will then therefore fly with great rapidity towards the conductor; direct the pointed end of the wire towards the ball, and it will keep it fixed to the conductor, by continually supplying it with the resinous power; remove the wire, and the ball parting with its resinous power to the conductor, in exchange for the vitreous, of which the conductor has the greatest quantity, it becomes electrified therewith, and repelled from the conductor.

Analogous to the foregoing experiment is the following, with a piece of linen thread, which, from the vivacity of its motions is termed the *animated thread.* For this purpose I present a fine thread towards the electrified conductor, and it will fly backwards and forwards in a very pleasing manner, according as it conveys the vitreous power to the hand, or the resinous to the conductor, to which it will sometimes be affixed for the same reason as the ball in the preceding experiment. Let a thread hang from the conductor, and present another towards it, they will attract and join each other: present any non-conducting substance, as a brass ball, near the two threads; the lower one, or that held by the hand, will fly from the ball, while that affixed to the conductor flies towards it. The vitreous atmosphere of the conductor repels the vitreous power of the ball into the hand, and draws the resinous power into it; the ball being therefore resinously electrified, attracts the upper thread, but repels the lower one, which is in the same state with itself, as acted on by the same causes. In this experiment, the afflux and efflux of the two powers is, as it were, visible to the senses. You will find, that a contrariety of power must always precede, and is absolutely necessary to all electrical attraction, and, indeed, to every communication of electricity.

I suspend a small copper plate from the conductor; underneath this, and at a small distance from it, is a larger copper plate which rests upon a proper stand, on the lower plate I put a leaf of gold, turn the cylinder, the leaf rises upon the plate, and expands itself into a perfect plane, with one corner opposite the upper, the other corner opposite the under plate, moving quickly upwards and downwards between both; I lower the under plate by degrees, the motion of the leaf has now ceased, and it remains suspended in the air between the two plates; darken the room, and you will find the leaf supported, as it were, by pillars of fire; now, as no substance can be thus supported in equilibrio, but by the joint action of two forces acting in opposite directions, we have a clear proof that there must be two forces thus acting in the present instance.

Place some small paper figures of men, women, &c. on the lower plate, *plate* 1, *fig.* 7; turn the cylinder, and you see the images rise up, moving from one plate to the other. They generally move in an erect position, sometimes leaping one upon another, and moving in such a variety of postures, as to afford much entertainment. The dance between them has so droll an appearance, if well-conducted, that there are few who can look upon it without laughing. I have before observed to you, that there are two powers in electricity; now, the heads of the puppets are electrified with the one power, and the feet with the other; they are therefore repelled at both ends, and never come in contact, unless the lower part of one touch the higher part of the other, and then they approach and stick together.

The foregoing experiment is not only amusing, but instructive: you will find that a very minute alteration in their figure will make the images dance between the plates, or remain fixed to the upper or under plate; for this end, the upper part should be always so much larger than the lower part, as to contain a part of the power going in, as much greater than what goes out, as will be equal to the gravity of the paper: with a little practice, you will be able to make one of them dance for some minutes without touching either the top or bottom plate.

To further illustrate the affluence and effluence of the two powers, dry the head of one of the images, and the power thrown out from the conductor cannot enter that puppet so freely, as the contrary power from the lower plate enters the feet, which are not so dry; the image will therefore ascend to the upper plate, and remain there: reverse the experiment, by drying the feet and wetting the head, and the image will remain fixed to the lower plate. These, as well as many other experiments, will prove to you, that it is not the mere component parts of the body that are acted on in electrical experiments, but that it is the different states of the electrical powers inherent or adhesive to the body which occasion the effects; and that, strictly speaking, it is the opposite powers only that attract each other, and that no substance is ever attracted, until it has acquired a contrary electricity.

If the two powers cannot be put in action, the experiment will not succeed; for, if you place your images on a clean dry pane of glass, and hold this under the upper plate, first removing the lower plate and its stand, you will find that the images will not be put in motion, notwithstanding you continue to turn the machine. Glass does not transmit the two electricities, and therefore no contrariety in the electric state of the image can be occasioned, and consequently it will not move backwards nor forwards;

between the two plates. But, if any means be used to cause an exchange in the powers, as by holding your finger under the glass plate, they will be driven backwards and forwards as before.

Here is a small apparatus, consisting of three bells with two clappers between them, *plate* 1, *fig.* 6; they are suspended from a straight piece of brass, the two outer ones by small brass chains, the middle bell and the clappers are suspended on silk; from the middle bell there is a chain which goes down to the table; I hang the bells on the conductor, and turn the machine, and the clappers fly from bell to bell, affording you a pleasing peal by electricity. The power from the conductor is conveyed down the chains to the exterior bells; by means of the chain, the exterior bells repel the same power with which they are electrified from the bell or clapper, which, on the powers being thus separated, are driven to the outer bell by the contrary power which sits in from the table, &c. through the middle bell; the ball becoming electrified with the same power as the middle bell, is driven back, and will continue going from one to the other, as long as the outside bells are kept in an electrified state by the machine.

If you take hold of the silk cord which is tied to the lower end of the chain that comes from the middle bell, and thereby raise that chain from the table, the ringing will immediately stop; for, silk being a non-conductor, prevents the afflux and efflux of the fluids.*

As the apparent attraction and repulsion of all light bodies depend on the afflux and efflux of the separated powers, I shall not, in shewing you every experiment, enter into a detail of these circumstances, hoping that what I have already said will render that point sufficiently clear. I turn the machine with one hand, and hold the other about three or four inches from the end of the conductor; drop a small lock of cotton upon the hand near the conductor, and the cotton immediately jumps from my hand to the conductor and back again, stretching itself out both ways into an extended form, and moving so quick that you will scarcely be able to perceive its form.

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* Eight bells, forming the octave, are sometimes placed on a round board with a clapper and fly, and set in motion also by the electric fluid, which afford a pleasing musical effect. EDIT.

Here is a small toy, somewhat resembling a hog; I have coated it with ermine, in the hairs of which I have inserted a few pieces of cotton pulled out, so as to be of a considerable length; place this upon the conductor, I turn the machine, and the hairs of the ermine diverge, and the pieces of cotton are discharged and driven some feet from the conductor. This apparatus, by thus discharging its quills, may be called with propriety the *electrical porcupine.*[*]

Few branches of philosophy afford so much entertainment as electricity; here the useful and the agreeable are intimately blended, and while you are investigating science, you are entertained by the variety and beauty of the experiments. It was the strong attractive and repulsive powers exhibited by electricity, that first engaged the attention of natural philosophers; by these they were led on to pursue the subjects, as it were by enchantment, and have been richly rewarded by discoveries both interesting and important.

A few more of the leading experiments, which have been so advantageous to science, will not be uninteresting.

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[*] Communicated by Mr. *Wisset.*

METHODS OF IMITATING THE PLANETARY MOTIONS.

Rackstrow's orrery consists of small glass balls blown very thin; they are placed on a wooden board, and environed with circles of brass wire insulated with sealing-wax, or glass, of such a height that the center of the balls may be nearly parallel to the wire circles. One of these circles may represent the orbit of Saturn, another that of Jupiter, &c. the circles being connected with the conductor of the machine by a wire, and a glass sphere placed between each, the spheres will perform their revolutions round their orbits, and at the same time acquire a rotation round their axes.

When the machine is set in motion, the balls will be first attracted to the brass circles, by which means the point that touches the brass circle will become electrified, and be immediately repelled; other parts will in the same manner be attracted and repelled, by which means the glass ball acquires a kind of spinning motion on its axis, at the same time it must have a progressive motion round the circle.

Provide a ball of cork about three quarters of an inch in diameter, hollowed out in the internal part by cutting it in two hemispheres, scooping out the insides, and then joining them together with paste. Having attached this to a silk thread, between three and four feet in length, suspend it in such a manner that it may just touch the knob of an electric jar, the outside of which communicates with the ground. On the first contact, it will be repelled to a considerable distance, and after making several vibrations, will remain stationary; but if a candle is placed at some distance behind it, so that the ball may be between it and the bottle, the ball will instantly begin to move, and will turn round the knob of the jar, moving in a kind of ellipsis, as long as there is any electricity in the bottle. This experiment is very striking though the motions are far from being regular; but it is remarkable, that they always affect the elliptical rather than the circular form.

Cut a piece of India paper in the shape of an isosceles triangle, whose sides are about two inches long and two tenths of an inch in breadth; then erect a brass ball of two or three inches diameter on a brass wire one-sixth of an inch in thickness, and two feet six inches long, on the prime conductor; electrify the conductor, and then bring the obtuse end of the piece of paper within the atmosphere of the ball; let it go, and it will revolve round the ball, turning often on its own axis at the same time.

TUMBLER AND BALLS.

Put a pointed wire into one of the holes which are at the end of the conductor, Y Z, *plate* 1, *fig.* 1, hold a dry glass tumbler over the point, then electrify the conductor and turn the tumbler round, that the whole interior surface may receive the fluid from the point; place a few pith balls on a metallic plate or the table, and cover them with this glass tumbler: the balls will immediately begin to have a rapid motion upwards and downwards, as if they were animated, and will continue to move for a long time.

ELECTRICAL FLUID UNIVERSALLY DISSEMINATED, AND IN CONTINUAL ACTION.

That the electrical fluid is universally disseminated and in continual action, has long been the opinion of those who have paid attention to it. To prove this to others, various instruments have been contrived to detect the smallest variations, and discover the minutest signs of its existence; these have been generally named *electrometers*; and among these, that described by the Rev. Mr. *Bennet*, of Wirksworth, may be considered the first, as being by far more sensible than any of the rest. This is one of them, *plate* 2, *fig*. 1.

The foot, A, is made of brass, and about three inches high, that you may move the instrument by without touching the glass; the cylindrical glass, B, in which the gold leaf is suspended, is about five inches high, and one in diameter; the cap, C, is made of brass, and flat on the top, that the various substances whose electricity is to be examined may be conveniently placed thereon. The diameter of the cap is larger than that of the glass, and its rim is about an inch deep, hanging parallel to the glass, in order to keep it clean and dry; within this is another circular ring that goes over the glass, and is lined with a soft substance to make it fit close within this rim; at the center of the cap a tube is fixed, wherein the peg is placed to which the two slips of gold leaf or silver are fastened.

If there were no glass, the gold leaf would be so agitated by the least motion of the air, that it would be entirely useless, To prevent the gold leaf from being attracted and torn by flying to the glass, two pieces of tin foil are fastened, with varnish on the opposite sides of the glass, where it may be expected to strike these slips and carry off the superfluous electricity, and increase the sensibility of the instrument.

The experiments made with this instrument, not only shew that the electrical fluid is universally disseminated, but that the smallest motions in nature disturb its natural equilibrium, and separate the two powers, and thus manifest it to our senses. That this fluid is the etherial medium, or element of fire, connected with some material substance, can scarcely now be doubted: if so, all the oscillations in nature put it in action, or, what is more probable, it is the cause of those oscillations. Mr. *Bennet*'s electrometer will prove to you, that all solution of continuity excites electricity: and I believe there is scarcely any instance where its action is manifested, but what may be traced to this source. In other words, every thing that will increase one power, or lessen the other, produces electric signs.

Not to interrupt too much the progress of our Lectures, I shall relate to you some of Mr. *Bennet*'s experiments.

1. Powdered chalk was put into a bellows, and blown upon the cap, C, of the electrometer; the stream of chalk produced vitreous electricity, when the nozzle of the bellows was only six inches distant from the cap; but the same stream electrified it with the resinous power, when at the distance of three feet. In this experiment, the quality of the electricity seems to be changed by dispersing or widening the stream, and making it pass through a longer tract of air; it is also changed by passing the stream through a bunch of fine wires, silks, or feathers, placed in the bellows: it is resinous when blown from a pair of bellows, the iron pipe being taken off to enlarge the stream. This last experiment seems to answer best in damp weather. The vitreous electricity generally remains; but in the resinous, the leaf gold collapses as soon as the cloud of chalk is passed.

2. A piece of chalk drawn over a brush, or powdered chalk put into a brush, and projected on the cover, gave resinous electricity. The electricity was not permanent.

3. Powdered chalk blown with the mouth, or a pair of bellows, from a plate placed upon the cover, gave a permanent vitreous electricity. If a brush is placed upon the cover, and a piece of chalk is drawn

over it, when the hand is withdrawn, the leaf gold gradually expands with vitreous electricity, as the cloud of chalk disperses.*

OF THE FRANKLINIAN THEORY.

It was not my intention at first to have particularly noticed the defects of this theory; but, as some late writers have endeavoured to conceal its errors, either by giving up some of the most essential parts, or by endeavouring to bend facts to accommodate to this theory, it became necessary to point out a few of its defects and inconsistencies. Many parts thereof, I conceive, would never have been accredited, if it had not been necessary for party purposes, to establish the author's reputation as a philosopher.†

From hence we may learn, that all new discoveries should be admitted with caution, for they are seldom accurate and free from errors; we are too often apt to be led away by glimmerings of light, or even false views of objects, which are often of worse consequences than a total want of knowledge.

I shall enumerate the leading principles of the Franklinian system, those which have always been considered in that light by the best writers and ablest advocates in favour of this system; and we may, therefore, justly conclude, that whosoever gives up any of these, so far abandons the principles on which it is founded.

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* A curious and useful machine, called a *doubler*, has lately been invented by the Rev. Mr. *Bennet.* It is an instrument by which the smallest quantity of positive or negative electricity, or the vitreous and resinous, may be continually doubled till perceivable by common electrometers, or by visible sparks. It has in its mode of action been improved by Mr. *Nicholson.* For a description of which, see our Author's Essays on Electricity, 4th edition, p. 414. EDIT.

† On this head, the anecdotes to be related are numerous and curious.

1. That the operations of electricity depend on the action of a simple homogeneous fluid.

2. That the electric matter violently repels itself, but attracts all other matter.

3. That glass and all-other electrics, though they contain a great quantity of electric matter, are nevertheless impermeable thereto.

4. That by the excitation of an electric, the equilibrium of the contained fluid is broke, and one body becomes overloaded with electricity, while the other is deprived of its natural share.

5. Electricity is positive when a body has more than its natural share; the electricity is negative, when a body has less than its natural share.

With respect to the first position, you will find, that its friends can bring no experimental proof to shew the homogeneity of this fluid, or its actions; but, on the contrary, they are forced by experiment to acknowledge a contrariety of state in every operation.

The second position is not only destitute of proof, but contradictory to all experiments; for the electric fluid never attracts matter as such, but only on account of the state of the electric matter therein. It is not repulsive of itself; the appearances, on which this idea is grounded, are owing to the resistance of the air. Both attraction and repulsion cease where the powers can unite without this resistance.

In the course of these Lectures, you will see many experiments that prove the permeability of glass. The notion of its impermeability is altogether hypothetical, for it is not supported by any one determinate experiment, and is contrary to every electrical appearance. You will find the ideas of the Franklinians concerning it quite contradictory, some allowing that its influence acts through glass, yet maintaining that it is impermeable thereto; others allowing certain kinds of glass to be permeable. Indeed, you may gather from their writings, that the best, and the worst vitrified glass, that cold and warm glass are all more or less permeable.*

The fourth and fifth principles may be considered as one, for they are so intimately connected, as not to be separated: whatever weakens the proofs of the one, diminishes those of the other. The whole Franklinian hypothesis falls to the ground, if the supporters thereof cannot prove, that positive electricity is a superabundant quantity, an accumulation of the electric matter in the body positively electrified, and negative electricity a deprivation of the quantity of this matter natural to a body.

Now, in the first place, we have strong reasons to suppose, that every electric appearance is occasioned by the fluid being in a divided and weakened state; but putting this consideration out of the question, let us ask the supporters of the Franklinian system for a proof of this position, and, strange to tell, you will find it destitute thereof. You will find them only reasoning in a circle, proving the thing itself; a method from which no conclusion can be drawn. Thus, for instance, a body that is positively electrified, attracts one that is negatively electrified, because the first has too much, and the other too little electricity. Demand how they prove one has too much, and the other too little of this fluid and they answer, because they attract each other!!!

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* *Lyons*, Remarks on the leading Proofs of the Franklinian Theory. *Milner's* Experiments and Observations on Electricity, &c. &c.

According to their principles, the electrical fluid is as active when redundant, as when deficient; and yet when it is in an intermediate state, it is inactive. "Two light bodies suspended in contact, in their natural state shew no signs of electricity; take away part of their electric fluid, and they repel each other; take away still more, and the power of repulsion increases; so that the more a body is deprived of its electric fluid, the more active and extensive is its electric action."*

Another mode by which they endeavour to support their system is, by shewing that the electric fluid always moves in one direction, that is, from the positive to the negative. Now it can be proved, as I think it has already been in a great degree, that there are two powers acting in contrary directions; the negative electricity will turn out to be a positive active power, and the Franklinian hypothesis will fall to the ground, being destitute of any proof. I shall hereafter shew you, that in the discharge of the Leyden phial, there is not only a power acting from the inside to the outside, but also at the same instant a power acting from the outside to the inside. Whosoever allows two currents acting in opposite directions, whatever may be his pretences, gives up the Franklinian theory, and confesses himself unable to maintain it on the original principles laid down by the author, and vindicated by *Canton*, *Le Roy*, *Priestly*, *Becket*, *Henly*, *Beccaria*, *Cavallo*, &c. &c.

Further proofs of the inconsistency and weakness of this theory will be shewn in the course of these Lectures; but they are so numerous, that to expose them all, would occupy too much of our time; one or two more I shall mention here; thus you will find Dr. *Gray*, in the Philosophical Transactions, proving

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* *Peart* on Electric Atmospheres.

Dr. *Franklin*'s account of the charge and discharge of the Leyden jar to be erroneous; yet endeavouring to support the weakest part thereof. Mr. *Brooke*, in his Miscellaneous Experiments, has shewn, what Mr. *Eeles* has shewn years before, and that by reasoning *a priori* from his theory, contrary to the ideas of the best judges and friends of *Franklin*'s theory, that during the time of charging a Leyden jar, both inside and outside have the same kind of electricity. Mr. *Read* has demonstrably proved, by a method previously pointed out by Mr. *Eeles*, that in the discharge of the Leyden phial, a vacuum forming a part of the circuit, the electric matter moves in contrary directions; yet such is the force of philosophic authority, that both Mr. *Brooke* and Mr. *Read* endeavour to bend these facts to support a theory, with which they are utterly irreconcileable.

OF THE ELECTRIC SPARK, AND OF THE INFLUENCE OF POINTS.

I bring the knuckle of my hand near the conductor, and a spark with the appearance of fire passes between the conductor and my hand, and I feel a sensation somewhat resembling a stroke from the end of a small wire. I remove my knuckle further from the conductor, and the spark is longer, forming several curves in its passage, having the exact appearance of a flash of lightning. In this experiment, as much of one power passes from the finger to the conductor, as of the other from the conductor to the finger. No spark will pass unless there can be this interchange of power; and the spark is always from those parts where the exchange can be most readily effected.

Where the two powers can be easily changed, which is the case with pointed metallic bodies, the equilibrium is restored silently, and the conductor is of course gradually divested of its electric appearances: but where the surface is large, and a contrary state is not so easily produced, the electricities are as it were compressed, and do not escape till they have acquired power to overcome the intervening space of air, when it explodes, and the spark is vivid like lightning.

As soon as I present a needle, or any other fine pointed substance, to an electrified body, the electric fluid is urged there with great velocity, and the electricity is said to be drawn off. This drawing off, however, does not extend to any great distance, not even all around the electrified body, if you keep turning the machine at the same time that you present the point. To prove this, place the wire, to the end of which a number of fine threads are fastened, in one of the holes on the top of the conductor; turn the machine, the threads on the wire diverge, and spread out like rays proceeding from a center; now present a point towards one side of the conductor, but at some distance from it, and you see the threads on one side lose their divergence and hang down, while those on the other side continue to diverge.

Indeed, a point never acts beyond the electric atmosphere, nor does it act upon that any further than it is immerged therein, and then only so far as it can draw the resinous power through them, and part with so much of the vitreous to them. Suspend a piece of down, or a small ball, by silk, so that it may hang against the side of the conductor; when you turn the machine, it will be electrified, and fly to the extreme part of the conductor's atmosphere; now stop turning, and bring a point towards the outside of the down, and instead of the down being driven in towards the conductor, it it will fly to the point, till it has exchanged powers with the point; then it will fly to the conductor, and be electrified, and again repelled; when it comes to a certain distance from the point, it will fly towards it, and be electrified thereby, and so on, as long as the conductor remains electrified.

When the down is on the verge of the electric atmosphere, immerge your point in the atmosphere, and you will see the down approach the conductor in proportion to the immersion of the point, and this is as often as you move the point forward to the conductor, but no further; so that the point acts only while in contact with the electric atmosphere

While the machine is turning, and the point immerged in the electric atmosphere, there is a strong stream of the resinous power flowing in from the point to the conductor, and that in proportion to the vitreous power carried off by the point. If this stream meets an electrified cork ball, or piece of down, it will change their powers, and electrify them with the resinous power, by which means they are attracted to the conductor, and will be fixed there by the continual stream of the resinous power; draw back your hand to lessen the resinous stream, and you will see the down move from the conductor by degrees, and remain between the two powers, without being forced to the conductor, or able to fly far therefrom. The foregoing experiments are most decisive with a weak electricity.

That the spark or passage of the electrical fluid, from the prime conductor to any conducting substance, depends upon the greater or less degree of difficulty in producing the contrary current, is further evinced by placing a point at the end of a piece of sealing-wax, and at a small distance from that part of the metal in contact with the sealing-wax, paste a small round piece of tin-foil, at a little distance from this another piece, &c. put your finger upon one of the pieces of tin-foil, that is furthest from the metallic point, and present the point towards the conductor, and you will find that it does not act near so powerfully, nor at so great a distance as in the former case; and if you approach it sufficiently near the conductor, a spark will pass between it and the conductor. Connect your finger immediately with the metal, and you will not be able to obtain a spark, and the electric appearances of the conductor will be sooner destroyed by the quicker interchange of the contrary powers.

As the spark, which explodes, and is bright in the air, becomes silent, faint, and diluted in vacuo; so, on the other hand, the electricity, that would pass imperceptibly in air, may be made to explode, and become bright, by passing it through mediums more resisting than air.

I place a metallic vessel nearly filled with common oil on the conductor; I shall immerge therein a point, from which, in the open air, I can scarcely obtain any visible appearance, and you see that, under these circumstances, strong sparks pass between the point and the bottom of the vessel, and the oil is thrown into a violent ebullition, by the afflux and efflux of the two electrities.

Here is a pointed wire suspended vertically from the conductor, the point being downwards, from which I can obtain no spark, though the machine is acting powerfully. I immerge it in a small bottle of oil, and put my thumb opposite the point; the spark is loud, the oil is curiously agitated, and, if you examine the bottle, you will find it perforated.

Round this glass tube, *plate* 2, *fig*. 2, at small but equal distances from each other, pieces of tin-foil are pasted in a spiral form from end to end, hence it is called the spiral tube; this tube is inclosed in a larger one, fitted with brass caps at each end, which are connected with the tin-foil of the inner tube. Hold one end in the hand, and apply the other near enough to the electrified prime conductor to take sparks from it, a beautiful and lucid spot will then be seen at each separation of the tin-foil; these multiply, as it were, the spark taken from the conductor; for if there was no break in the tin-foil, the electric fire would pass off unperceived.*

Here are several spiral tubes, *plate* 2, *fig.* 4, placed round a board, a glass pillar is fixed to the center of the board, on the top of this pillar is a brass cap, carrying a fine steel point, to support a wire furnished at each end with a brass ball, and nicely ballanced. I place this under a ball proceeding from the conductor, so that a continued spark from this ball to the center of the suspended wire, gives this wire a rotatory motion, and the balls in their revolution will give a spark to each spiral tube, which, in its passage from one spot to the other, forms a most beautiful species of illumination.

Take this piece of silvered leather, and put it round your head, and then stand upon the stool with glass feet, connecting yourself with the conductor by a chain. If, while I turn the machine, any one pass their knuckles near the hoop of leather moving them round it, the leather will be beautifully illuminated, and brisk flashes of electric lightning will pass between the knuckles and conductor. This experiment has been termed the *diadem of beatification.**

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* These sort of experiments must be exhibited in a perfect darkened room, and then the effect is incomparably brilliant and pleasing. Pieces of tin-foil placed on slips of glass with their intervals, forming names and various figures, will have very pleasing effects when exhibited by the electric spark. EDIT.

Spirits of wine may be easily fired by the electric spark; to insure success in making the experiment, it is best either to heat the metallic ladle into which the spirits are to be placed, or else just to fire the spirits, and blow them out, a few seconds before they are electrified. This experiment may be performed two ways: 1. By placing the ladle with the spirits on the conductor, and then taking a spark through the spirits, which will set them on fire. Or, 2. If a person stands on the insulated stool, *plate* 2, *fig*. 6, and hold in one hand a chain or wire from the electrified conductor, and in the other a spoon with the spirits of wine, and another person on the floor brings his knuckle, or a brass ball, quickly to the surface of the spirits, they will be instantly in a flame. You may vary this experiment thus: 3. Let the electrified person on the stool hold the spirits as before, while another person, standing also on an insulated stool, holds in his hand an iron poker, one end of which is made red-hot; he may then apply the hot end to the spirits, and even immerge it in them, without firing them; but he may set the spirits on fire, with either the hot or cold end, provided the hot end be not worn to too sharp a point. The spirits could not be kindled while the person was insulated, because the electric powers could not in that case be separated; and hot iron, immersed in spirits, will very seldom or never set them on fire.

You must have already observed, from what you have seen, that when the quantity of electricity is small, it is incapable of striking at a considerable distance, and the spark appears straight; but when it is strong, and capable of striking at a greater distance, it assumes a crooked zig-zag direction. In every electrified conductor, the electricity always escapes from that part of the surface, where the powers are most separated. The spark is of a different colour according to the density; when it is rare, it appears of a bluish colour; when more dense it is purple; when highly condensed, it is clear and white like the light of the sun. The middle part of an electric spark, when the two powers meet, often appears diluted, and of a red or violet colour, the ends are more vivid and white; when very strong, it will branch out and divide into many parts.

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* For a further and greater variety of experiments on these principles, see my Essay on Electricity, last edition.

OF MOTIONS PRODUCED BY THE ELECTRIC STREAM.

Whenever there is an efflux of one power of electricity, there is also an afflux of the other power, if any conducting substance is placed so near and in such circumstances, as that it can be drawn therefrom.

Here is a brass cross, *plate* 2, *fig*. 5, supported on a point like a compass needle, with each of its points bent the same way; place this upon the conductor, and as soon as I turn the machine, it turns with great rapidity, but always from the points, because the electric fire, flying off from the points, acts forcibly on the air, and is consequently re-acted upon, which occasions the motion. Take the fly and its point, and hold it in your hand under the conductor, and it will turn in the same manner, by a stream of electricity of a contrary power to that thrown off from the conductor, which is drawn in from you, and delivered from the points of the fly to the conductor. Now insulate the fly, and place it at the same distance from the conductor, and it will not move, because no electricity can be drawn through it; but hold a pin near it, and the fly will immediately begin to turn, as it draws a sufficient quantity of electricity from you through the pin.

On this principle, those who are desirous of blending agreeable entertainment with philosophy, may contrive a variety of curious machines, whose motions may be produced by the electrified stream, which will afford much entertainment to those who can relish domestic innocent amusement; and by these, science will be benefited; for to render any science familiar, is to render it prevalent, and the more it prevails in practice, the more likely it is to produce useful discoveries.

If small boats, or little swans, &c. are made of cork or light wood, they may be attracted, and made to swim in any direction, by applying a finger towards them; a fine needle stuck into the end of the boats, in the manner of a bowsprit, will cause them to be repelled from the hand held over it, and they may be steered by it, stern foremost, to what point of the compass you please. The boats might have the addition of sails to them, and might then be made to move briskly before an electrical gale, from the point of a wire held in the hand.

The operator in these tricks would certainly be looked upon as a magician, if the electrical machine is kept out of sight. But a more striking sight would be a number of these boats, with each of them a twirling fly, about an inch in length, fixed to the top of the mast; the hand held over them would set them all in motion; in the dark they would appear as so many rings of fire, moving in various courses, and following the hand in any direction.*

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* *Becket* on Electricity.

OF THE DIFFUSION AND SUBDIVISION OF FLUIDS BY ELECTRICITY.

From experiments made by Abbe *Nollet*, it appears, that electricity augments the natural evaporation of most fluids, particularly of those which have the greatest tendency to evaporate; that it, in this respect, acts most powerfully upon the fluids when they are contained in metal vessels; but it never makes any fluids evaporate through the pores either of metal or glass. When fluids, that are passing through capillary tubes, are electrified, the stream is subdivided; and if the tube be less than one-tenth of an inch in diameter, their motion is generally accelerated.

I suspend this metal pail, to the bottom of which a capillary tube is adapted, to the conductor; before I turn the cylinder, the tube carries off the water only by interrupted drops; but on turning the cylinder, and electrifying the water, the droping from the tube is changed into a continued stream. On applying my finger to the conductor, the electricity is interrupted, and the water again only descends in drops: my finger taken away, the water runs in a diverging stream: darken the room, and you perceive a fiery stream descend from the tube. This experiment has been termed the *electrical jet de feu.*

Insulate two pails with capillary tubes; connect one with the cushion, the other with the conductor; turn the machine, and the water, which is dispersed into very minute particles, when they are near enough, is brought together by the effort of the two powers to join each other; the drops coalesce and come down like a heavy shower of rain.

I place a drop of water on the conductor, and turn the machine. On presenting my knuckle towards this drop, long zig-zag sparks are obtained from the drop of water; the drop takes a conical figure; my knuckle is wetted. The spark was considerably longer than could be obtained from the conductor without the water.

Fasten a piece of good sealing-wax to the ball on the end of the conductor, but place it in such a manner that it may be easily set on fire by a taper; set it on fire while I turn the machine; the wax becomes pointed, and shoots out an almost invisible thread to a considerable distance. If you receive the filaments on a sheet of paper, the paper will be covered in a very curious manner by the electrified wax threads; the wax flying to those places where it can unite with the contrary power.

LECTURE XLVII.

OF THE LEYDEN PHIAL.

Dr. Priestley has well observed, that electricity has one advantage over most other branches of natural philosophy: it furnishes matter of entertainment for all persons promiscuously, while it is also a subject of important speculation for the most philosophic minds. Neither the air-pump, nor the orrery, nor any experiments in hydrostatics, optics, magnetism, &c. ever brought together so many, or so great concourses of people, as those of electricity have singly done.

If you only consider what it is in objects that makes them capable of exciting that pleasing astonishment, which has such charms for all mankind, you will not wonder at the eagerness with which persons of both sexes, and of every age and condition, run to see electrical experiments. For here you see the course of nature overturned to all appearance, and by causes seemingly inconsiderable.

For it exhibits to you bodies rising and falling, moving this way and that, and suspended by others contrary to the principles of gravitation, and this by powers which have been put in action only by a very slight friction. Here you may see a piece of cold metal, or even water or ice, emitting strong sparks of fire, so as to be able to kindle many inflammable substances. Nor will you find any thing more astonishing than what I am going to exhibit to you. You will find a common glass jar, after a little preparation, capable of giving a person such a violent sensation, as nothing else in nature can give; and that the discharge of the bottle is attended with an explosion like thunder, and a flash like lightning.

Before I enter into the theory of charged glass, I shall shew you in what manner it is charged and discharged. This jar is coated on the outside and lined on the inside with tin-foil, to about two inches short of the top, which is stopped with a piece of wood, see *plate* 1, *fig*. 12. A wire passes through the wooden top, and is connected underneath with two other wires, which are bent so as to touch the inside coating of the jar; a smooth ball is fixed on the top of the wire.

To discharge the jar without receiving what is called the shock. For this purpose two instruments have been contrived, one called the *common discharging rod*, *plate* 1, *fig*. 8, which is nothing more than a semicircular brass wire, furnished with two brass balls, one at the end of each wire. The other, which is of very extensive use in electrical experiments, is called the *jointed discharging rod*, *fig*. 9;

it is furnished with a glass handle; the wires are moveable, and may be set to any given distance by means of the joint; the ends, to which the balls are screwed, are pointed.

Place the jar on the table, so that the ball on the top of its wire may be about one-eighth of an inch from the ball and wire placed in the prime conductor Y Z, *plate* 1, *fig*. 5. Turn the machine, and sparks will fly from the ball of the conductor to the ball of the jar: continue turning as long as you perceive the fire pass between the conductor and ball of the jar; when it ceases, you may leave off turning, and consider the jar as charged. This done, take hold of the discharger by the middle, and apply one knob first to the outside coating near the bottom, and keeping it there, put the other to the ball of the jar, and it will be discharged of its fire with a loud snap, but the person who holds the discharger feels nothing from the discharge.*

Now charge the jar, and touch the outside coating with one hand, and then bring the other to the ball of the jar, you will then act the part of the wire discharger, and receive a shock; it has affected you through your arms and breast, and the phial is discharged. You may easily contrive, by way of recreation, to render the surprize occasioned by this experiment more entertaining, by connecting a chain with the outside coating, and concealing it under a carpet, at the same time connecting another with the top,† placing it in such a manner, that a person may put his hand upon it without suspicion, at the same time that his feet are upon the other wire; but great care should be taken, that these shocks are not too strong, and that they be not given to all persons indiscriminately.

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* With young beginners this should be particularly attended to, as they will thus avoid any disagreeable effect of a shock. No shock can be received but from a charged jar, or a considerable portion of a glass surface covered with tin-foil. Edit.

† This may be conveniently done by what is called a medical electrometer, either fitted to the ball and wire of the jar, or to the conductor.

When a single person receives a shock, the company is diverted at his sole expense; but all contribute their share to the entertainment, and all partake of it alike, when the whole company form a circle by joining their hands, the person at one extremity of the circle touching the outside coating, while he, who is at the other extremity, touches the ball of the jar. All the persons who form this circle being struck at the same time, and with the same degree of force, it is pleasant to see them all start at the same moment, to hear them compare their sensations, and observe the very different accounts they give.

It is often convenient, sometimes necessary, to know the state of a jar with respect to the charge; Mr. *Henly*'s quadrant electrometer is the best instrument yet known for that purpose. It consists, *plate* 1, *fig.* 17, of a perpendicular stem formed at top like a ball, and furnished at its lower end with a brass ferril and pin, by which it may be fixed in one of the holes of the conductor, or at the top of a Leyden bottle. To the upper part of the stem, a graduated ivory semicircle is fixed, about the middle of which is a brass arm or cock, to support the axis of the index. The index consists of a very slender stick, which reaches from the center of the graduated arc to the brass ferril; and to its lower extremity is fastened a small pith ball nicely turned in the lathe. When this electrometer is in a perpendicular position, and not electrified, the index hangs parallel to the pillar; but when it is electrified, the index recedes more or less according to the quantity of electricity.

OF THE THEORY OF THE LEYDEN BOTTLE.

I shall now endeavour to explain to you the theory of this mysterious bottle; and you will there see, that the electric powers, when in equilibrio, do really condense each other; and that one power always expands in proportion as the action of the other is withdrawn, or in proportion to the increase of one power, and the diminution of the other; and that when the bottle is charged, it is equally electrified on both sides, but with different powers of electricity; and when a communication is made by a conductor, the increased power on the outside flies in, and the increased power within flies out, to make the powers equal within and without.

Place a Leyden bottle upon the insulated stand, form a communication between it and the conductor, give the machine a few turns, and both sides of the bottle will be electrified with the vitreous power, as you may easily prove, by touching them with down or a small ball suspended by silk; for, when this is electrified by touching the outside, it will be also repelled by the ball which communicates with the inside.

Place an insulated bottle so that the ball may communicate with the conductor; let a wire also be connected with the coating, so as to form a communication with the table. Now turn the machine, and, 1. On applying a cork ball, you will not find any signs of electricity in the coating, but you will find the ball, or inside, electrified with the vitreous power. 2. Remove the wire communicating with the table, and you will find the coating also electrified with the vitreous power; and this is as often as you remove the wire, till the bottle is full charged. 3. When the bottle is full charged, remove its communication both with the conductor and table, touch the coating, and the cork ball will remain suspended by it without any sign of being electrified; then touch the knob of the bottle with your hand, the cork ball will be strongly repelled from the coating, and be electrified with the resinous power. 4. Take another cork ball suspended by silk, and touch the knob of the bottle therewith, and the cork ball will be electrified with the vitreous power and repelled. 5. Now touch the coating with your finger, and the cork ball will be repelled much further by the ball; but that which is repelled from the coating, now flies towards it, and remains at rest, till you touch the knob of the bottle with your finger; it will then be electrified as at first, and be violently repelled; the ball which was electrified by the knob of the bottle will now fly towards it. . This change in the extent of the atmosphere of the different powers, takes place almost instantaneously as often as you touch the ball or coating.

Or you may connect the knob of the bottle with the conductor by a wire, and suspend a cork ball to touch the conductor; then touch the coating, and the ball will be repelled from the conductor, while that next the coating is attracted; touch the knob of the bottle, and the ball will be repelled from the coating and attracted by the conductor, and so on, as often as you touch the knob or coating.

From hence it seems plainly to appear, 1. That the bottle is electrified with the vitreous power on the inside, and the resinous on the outside. 2. That when the equilibrium of these powers is destroyed by lessening the quantity of one, the extreme part of the other expands itself into an extensive atmosphere; but the atmosphere of the lessened power is condensed, as appears by the cork balls falling close to the conductor and coating. 3. It remains to be shewn, how these powers came to be thus situated on the inside and outside of the bottle, or why they do not mix through the glass where they seem to have the greatest tendency to unite. Here it will be necessary to consider the separation of these powers between the globe and the cushion, for all the other phenomena are only consequences of the separation that takes place between these. Now, the cylinder parts with its resinous power to the cushion, in exchange for the vitreous; the conductor, in like manner to the globe, and the inside of the bottle to the conductor; and so the exchange would go on with the next conducting substance, but that the bottle gives some obstruction to the passage of the electrical powers; by which means, the vitreous power, which passes through the glass to the conducting substance upon the outside of the bottle, is carried off, together with the vitreous power of the coating, along the wire which communicates with the table, in exchange for an equal quantity of the resinous power brought back by the wire to the coating of the bottle; till at length, the resinous power on the outside is able to counterballance the vitreous power on the inside, and thus affords an opportunity for drawing off the resinous power on the inside of the bottle to the conductor; so that the bottle remains a partition between the two powers, and they cannot change place through the peculiarly constructed pores of the glass, while their surfaces are opposed in such quantities.

For, when the junction is made in the open air, or when their surfaces are opposed in any quantity, it is not done without violence, occasioning a loud noise and a flash of fire, while bursting through to meet each other; for, wherever the different powers unite in any quantity, they are much condensed.

The violent convulsion felt through the body by completing a circle with the hands, is only occasioned by the different powers passing in opposition through the same nerves. For, if one person touch the coating, and another the top of the bottle, the bottle will be discharged without giving either of them the shock. Now, it is very clear, that as much fire passed through either of them, as if each had singly discharged the bottle. But in this case, the fire is diffused through all parts of the body, and the fire brought in is drawn from all parts of the body; and, consequently, the nerve cannot be so much shocked as in the former case, when all the fire passes in opposition through the same nerves.

EXPERIMENTS ILLUSTRATING THE THEORY OF THE LEYDEN PHIAL.

Charge an insulated bottle, remove it from the conductor, and let a cork ball suspended by silk hang against the outside of the bottle; touch the outside or coating with your finger, the ball will not be affected; but, touch the knob of the bottle, and the ball immediately flies off, strongly electrified with the resinous power; and thus you may go on for a considerable time, altering the ballance of the powers within and withoutside the bottle, by alternately touching the top and the bottom of the bottle. The defenders of *Franklin*'s system will hardly say, it is the return of the positive electricity which electrifies the ball negatively. The fact is, that when you touch the top, you take a spark of the vitreous power from the inside, and, in exchange, give as much of the resinous power thereto; by these means, the force of the vitreous power within the bottle is lessened, which leaves the resinous power on the outside in greater quantity than the vitreous withinside, and consequently at liberty to exchange with any non-electric in contact with it; and thus the ball becomes electrified with the resinous power.

Charge a bottle fully, and remove the wire from the table, and make the coating communicate with the conductor instead of the knob, and then turn the machine, and the resinous power with which the coating is electrified becomes covered with the vitreous power, and you may take as many sparks from it as you please, without making any change in the charge of the bottle; for, when you stop turning, and remove the communication with the conductor, and touch the outside of the coating with the finger, all signs of the vitreous power disappear; and when the circle is completed, the bottle is discharged with as loud a report as it would have done before you applied the conductor to the coating; for, the vitreous power within the bottle being undisturbed, kept an equal quantity of the resinous power firmly fixed to the outside of the bottle.

But the case is different when you give the vitreous power from the inside an opportunity to escape. Thus, when the bottle is full charged as before, remove the wire that communicates with the table, and bring the coating in connexion with the conductor; after a turn or two of the cylinder, take a spark from the ball of the bottle, and you will find that it will fly to a considerable distance, often double the distance you can draw a spark from the conductor, because the vitreous power covering the resinous power on the coating, lessens the action on the vitreous power within the bottle, and therefore leaves that power greater freedom to fly off; but as you go on taking sparks, they gradually lessen, because after a few, the vitreous power in the bottle is lessened, and the resinous power within increased by the quantity received in exchange on every spark; and thus by a few sparks the bottle is discharged; but if you go on to take more sparks, the bottle will be re-charged with the resinous power withinside, instead of the vitreous, with which it was before charged.

Again, suppose fifty turns of the cylinder will charge your bottle, turn only twenty-five, and then remove the communication between the coating and table; and as you turn on, whether you continue the communication from the conductor to the top of the bottle, or shift it to the coating, you will find the bottle electrified on both sides with the vitreous power; remove the bottle from the conductor, and then discharge it with an insulated discharger, and you will find the bottle still electrified, both within and without, with the vitreous power; but this electricity will disappear, by touching either the ball or coating with your finger.

To illustrate further the reciprocal exchange of the electric powers, here is an insulated bottle with a wire proceeding from the bottle, at right angles to which is a wire for receiving a needle with reversed points; make the top of the bottle communicate with the conductor, and all the time the bottle is charging the needle will turn; but when the bottle is charged, the needle stops. Then touch the top of the bottle with your finger, or any conductor, and the needle will turn till the bottle is discharged. Now, while the bottle is charging, if you touch the needle with a piece of bog-down, or a cork ball, suspended by silk, you will find it electrified by the vitreous power, which flies off in exchange for the resinous power drawn in from the air to the outside of the bottle; and while the bottle is discharging, if you apply the down or ball in the same manner to the needle, you will find them electrified with the resinous power, which flies off from the outside of the bottle in exchange for the vitreous power drawn in through the points from the air; while the vitreous power from the inside of the bottle makes the same exchange for the resinous power through your finger, to make these different powers equal to each other, withinside and withoutside the bottle.

Place two Leyden bottles on an electric stand, with their coatings in contact; and while you charge one from the conductor, let a person on the floor touch the top of the other bottle with his finger; you will find the first bottle charged with the vitreous power inside, and the second with the resinous power inside. Now, the exchange here is evident; for, while the resinous power from the inside of the first bottle changes place with the vitreous thrown in from the conductor, the vitreous from the coating changes place for so much of the resinous from the coating of the second bottle; and the vitreous in that bottle changes place for so much of the resinous power drawn in through the man on the floor.

I charge a Leyden phial, and set it aside to be in readiness to ascertain the state of another. I now take the bottle with the projecting wires, *plate* 1, *fig*. 10, unscrewing the ball from the wire at the coating, and suspending a pair of pith balls therefrom. This done, I bring the knob of the bottle to the conductor; I work the machine, and the phial will charge slowly, and the balls will repel each other; while I am turning and the bottle charging, bring the knob of the first bottle towards the balls, and they will be repelled thereby. This plainly proves, that the outside of the bottle is electrified vitreously while it is charging, that is, with the same electricity as the inside.

Let us discharge the bottle with the projecting wires, and charge it again as before, and you will still find, that whilst it is charging, the balls will fly from the knob of the first bottle; I cease turning, and the balls cease to repel each other; they now touch each other, and again recede, but with a contrary electricity, for they are now attracted by the knob of the first bottle. This shews that the difference between the two sides cannot appear, while they are charging, or while vitreous electricity is forced through the jar.

Let us now discharge both bottles, in order to try another experiment, to determine the state of the outside during the charge. I first put the ball on the end of the wire of the bottle with the projecting wires, bring the knob thereof to the conductor, holding the knob of the first bottle against the coating of that with the projecting wires; by working the machine, both will be charged. As soon as they are pretty well charged, and while the machine is working, remove the first bottle from the other; after this is removed, cease working the machine as soon as possible. I now connect by a wire the two outside coatings, and bring the balls to each other. If, while the bottles were charging, the outside of that with projecting wires had been resinously electrified, the inside of the second would have been so also; and on their being thus brought together, both bottles would be discharged: but this is not the case, for the insides of both are charged with the vitreous electricity, the coating having exchanged powers with the bottle charged thereby. This experiment shews, that to consider one side of a phial to be positive, and the other negative, at the time they are charging, is erroneous.

The criterion of the resinous and vitreous electricity, as determined by the light on metallic points, gives full evidence in favour of Mr. *Eeles*'s theory, while it is directly opposed to that of Dr. *Franklin*. For you will here find, that during the time that the bottle is charging, the outside exhibits the sign of vitreous electricity. To prove this, I place a pointed wire at the end of the conductor, and place this apparatus with the sliding wire, *plate* 1, *fig*. 11, on one of the insulated stands, first removing the bottle therefrom; I then unscrew the balls from the projecting wires of the remaining insulated bottle, and also from the sliding wire, which leaves the points that were under the bottle exposed and ready for our operations.

Things being thus prepared, I place the insulated bottle so that the point, from the inside, may be about half an inch distance from that in the conductor, and let one of the points of the sliding wire be at the same distance from, and opposite to, the point projecting from the outside of the insulated bottle. I now turn the machine, and as soon as the charge begins, the signs of the electricities are visible, illuminating the points of the interrupted circuit. The point on the prime conductor gives the brush or sign of vitreous electricity; the sign on the point opposed to it on the knob of the bottle is resinous. The light from the wire, that projects from the coating of the bottle, is the brush, or vitreous ramified light; but that of the point opposed thereto is the star, or sign of resinous electricity, as they ought to be, according to Mr. *Eeles*'s theory, not " contrary to the kind or source of electricity from whence they proceed," which is the case on the principles of the Franklinian theory.*

EXPERIMENTS SHEWING THAT IN THE DISCHARGE OF THE LEYDEN JAR, THE TWO ELECTRICITIES RUSH INTO UNION FROM OPPOSITE DIRECTIONS.

The three first experiments I shall mention to you, were made by Mr. *Atwood*, of Cambridge, and were described by him in the Analysis of a Course of Lectures, which he read at Cambridge.

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* *Reid*'s Summary View of Spontaneous Electricity, p. 81, 82

He slightly charged the surfaces of an electric insulated plate, and discharged it through an interrupted circuit, formed of needles placed in a groove of wax, the distance between each needle was very small; the two powers were visible, on the discharge illuminating the points of the interrupted circuit, each power extending further from the surface contiguous thereto, in proportion to the strength of the charge; but when this was sufficiently strong to make the illuminations proceeding from each side meet, there was an explosion of the whole charge. The length of the interrupted circuit made by Mr. *Atwood* was twelve feet.

Mr. *Atwood* charged a cylindrical plate of air, under the receiver of an air-pump, and found that the more the air was exhausted from between the surfaces, the more readily and easily the powers united.

He made an exhausted receiver part of the electric circuit, and on using such charges as were not sufficient to form an explosion, he found the electric light proceeding in opposite directions from the parts communicating with the vitreous and resinous surfaces.

When a Leyden jar is charged but slightly, if you touch the coating with a finger of one hand, and at the same time bring a finger of the other to the knob of the jar, you will receive a smart blow upon the tip of each finger, but the sensation reaches no higher. Charge the jar a degree higher, and you will feel a stronger blow, reaching to the wrists, but no further. When it is charged somewhat higher, a severe blow will be received, but which will not reach beyond the elbows. Lastly, when the jar is strongly charged, the shock will be perceived at the wrists and elbows, but the principal blow is felt at the breast, as if a blow from each side met there. This plain and simple experiment of

Mr. *Symmer* obviously suggests the existence of two currents proceeding in contrary directions, accords with those of *Atwood* and *Volta*,* and is in direct contradiction to that assertion of the Franklinians, "that the same quantity of electric matter, which is thrown upon one of the surfaces of glass in charging, is driven from the other, and that in the discharge this accumulated quantity is restored to the deficient surface."

When a jar is charged very high, the electricities will often, in their endeavous to unite, force a hole through the jar, and push out the coating on both sides, sometimes melting it; the burr of tin-foil protruded from the middle of the glass strongly indicates, that the two electricities meet at the middle of the glass;† there also the greatest effort is exerted.

Mr. *Read* says, that when the charge for melting of fine wire is of a proper intensity to melt it into fine globules, he has observed the wire to be of a paler red heat in the middle than at the extremities, and the melting to begin at the middle, leaving a portion unmelted at each end. At other times, though less frequent, the wire was observed to be of a more glowing heat in two parts, and these were generally near the middle. These effects clearly shew, that the vitreous and resinous electricities of the charged jar meet in great force near the middle of the wire, which is directly contrary to the leading notions of *Franklin*'s theory.

The remarkable tendency of the divided fluids to unite, is often perceived in a full-charged Leyden bottle, at the upper edge of the outside coating, and at the edge of the cork on the neck of the bottle; rays of light darting from each, and soliciting as it were an union, and sometimes forming an actual circuit.

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* See my Essay on Electricity.

† *Read* on Spontaneous Electricity, &c. p. 44.

THE SAME PRINCIPLES CONFIRMED BY THE APPEARANCES OF THE ELECTRIC SPARK.

The electric spark appears of different colours according to its density; when it is rare, it appears of a bluish colour; when more dense, it is purple; when highly condensed, it is clear and white, like the light of the sun.

The middle part of an electric spark often appears diluted, and of a red or violet colour, while the ends are vivid and white; this appearance cannot be accounted for by the theory of a single fluid moving in one direction, but is a proof of two currents moving in opposite directions; the electric signs growing weaker where the two powers unite. Mr. *Read** has well, and I believe first observed, that the place of re-union is much less luminous, and in some cases quite dark; and that this is the natural effect of the union of the two electricities; at that point the distinctions of the vitreous and resinous cease, and there the electric light vanishes. These appearances are best observed, by viewing in the dark a strong electric spark passing between two bodies electrified with contrary electricities.

Though the appearances of the electric light on a point and ball, as well as of the electric spark, are subject to many variations, yet there are certain signs generally peculiar to each kind of electricity. For instance, if the resinous part of a spark be small, or what has been usually termed the luminous globule, then the middle part is generally of a purplish colour. When ramified rays issue from the vitreous part, then the resinous is more extended, stretching out towards the vitreous. When the vitreous and resinous electricities strike into each other in dense light, in various parts of the intermediate space, then their exact place of union is generally observable by a dark spot. Mr. *Read* with propriety considers the loss of light in any part of an electric spark, whether total or partial, as the immediate effect and constant signs of the re-union of the two electricities.

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* *Read's* Summary View of Spontaneous Electricity, p. 47, 48, and 49.

Mr. *Read* observes, that whether the resinous light assumes the figure of an oblong flame, or of a luminous globule, in either case the vitreous light is seen to approach, and unite with it in all possible directions. The effect of a vitreous surface appears to extend farther than that of a resinous surface.

THE OPPOSITE DIRECTIONS OF THE TWO ELECTRICITIES PROVED BY THE APPEARANCES OF THE ELECTRIC LIGHT IN VACUO.

Though I have already pointed out to you some experiments in vacuo that illustrate this point, yet those of Mr. *Read* are so decisive, that not to mention them, would be to deprive you of essential information on this subject.

For these experiments, Mr. *Read* used a glass tube, three feet seven inches long, furnished at each end with brass caps, one of the caps fitted to the plate of the air-pump; from each cap a brass wire, on which was a brass ball, projected within the tube; when this tube is sufficiently rarefied, the charge of a Leyden phial will readily pass through the rarefied air.

In making these experiments, you must only slightly charge your Leyden jar; for, if the charge is strong enough to force the whole contents swiftly through the rarefied air, the motion of the fluid is too rapid, and the light too resplendent to permit an exact observation of its appearance.

On making the discharge in the dark, you will perceive, the moment the circuit is formed for that purpose, a light within the tube, but chiefly at each end. These lights are of the contrary kinds of electricity, and accord with the side of the bottle to which they are connected. You may sometimes perceive the two lights to have a manifest tendency to meet near the middle of the resisting medium. Mr. *Read* has observed the light within the tube to be considerably diminished in splendor where the two powers unite; and so it ought to be, for when the two electricities unite and regain their natural state, they lose their light, for it is only in a divided state that the electrical matter is luminous; the same appearances are produced in the tube by the simple spark, that is, the contrary electricities are observed at each end.*

But this is still further confirmed by a new observation and decisive experiment of Mr. *Read*'s. He suspended his exhausted tube in an horizontal direction, by silk lines from the ceiling;† one end was placed so as to receive an electric spark from the conductor of his machine; at half an inch from the other end, there was a metallic communication with the earth.

On turning the machine, the tube is filled with electric light, and continues so long as the action of the machine is continued. Mr. *Read* first observed, that the instant the supply ceases, the light divides near the middle of the tube, and flies back to the ends; fully evincing the truth of Mr. *Ecles*'s theory, by shewing that the light within the tube is not all of one kind of electricity; the tube includes both electricities in one appearance of light. The moment the action of the machine is discontinued, the afflux and efflux ceases, and each electricity returns to its own place, where the separation first commenced.

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* *Read*, p. 51, 52, 53.

† It is more convenient to insulate the glass tube or luminous conductor by glass pillars, as *plate* 1, *fig*. 13.

To ascertain beyond dispute, that the light within this kind of exhausted tube consisted of vitreous and resinous light, he made the following experiment. The glass tube was suspended as before, and two Leyden phials in an horizontal position, but lying on glass stands, were placed one at each end of the tube, with their metallic knobs nearly in contact with the metallic caps of the glass tube. In this disposition of the apparatus, the coating of one bottle is to receive a spark from the prime conductor, and the coating of the other a spark from the metallic communication with the earth.

On turning the cylinder, sparks were perceived to pass in the four intervals of air, and at the same time a luminous appearance within the glass tube. On removing the bottles, and examining their charges, they were found to correspond with the lights within the tube, to which they were opposed. One bottle was vitreously, the other resinously electrified.*

These experiments clearly prove, that there is at the same time one power acting from within, towards the outside of a charged Leyden phial, and another power acting from the outside towards the inside of the phial; and thus concur with others in shewing, that electricity consists of two distinct positive powers acting in contrary directions, and towards each other.

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* Mr. *Eeles* from his theory, pointed out, in 1758, the mode of making this experiment, and foretold what would be the result. This is only one among many instances, where, in reasoning *a priori*, he has pointed out results, that the Franklinians of the day denied.

Here is a glass coated flask from which the air has been exhausted, that you will find, on trial, to illustrate pleasingly the theory of electricity, *plate* 1, *fig.* 14.

From the experiments on the theory of the Leyden bottle, I shall now proceed to some entertaining ones with the same instrument. No electrical experiments answers so well the joint purposes of pleasure and surprize, as those that are made with the Leyden phial. And philosophers are so far from laughing at the astonishment of the ignorant at these experiments, that they cannot help viewing them with equal, if not greater astonishment themselves. There are indeed, as Dr. *Priestley* has observed, many electricians still living, who can well remember the times when, with respect to these things, they themselves would have ranked among the same ignorant and staring vulgar.

What would the ancient philosophers have said, what would *Newton* himself have said, to see the present race of electricians imitating, in miniature, all the known effects of lightning; nay, essaying to disarm the thunder of its power of doing mischief, and without any apprehension of danger to themselves, drawing lightning from the clouds into a private room, and amusing themselves at their leisure, by performing with it all the experiments that are exhibited by electrical machines?

One cannot indeed consider the present improved state of philosophy, without indulging, with the Rev. Mr. *Jones*, a wish to exhibit to the wise men and heroes of ancient times, some of those wonderful improvements which are now so familiar to us, but were totally unknown to them.

I would give, says he, to *Aristole* the electrical shock: I would carry *Alexander* to see the experiments upon Woolwich warren, and exhibit to him all the evolutions and firings of a modern battalion: I would shew to *Julius Cæsar*, the invader of Britain, an English man of war; to *Archimedes* a steam engine, and a reflecting telescope.*

Entertaining electrical experiments are not without their use, for they even give philosophic minds an opportunity of viewing things under different points of view, and often arrest the attention on objects which had before escaped their notice.

To strike a hole through a card. Having charged your jar, hold a card with one hand close to the coating of the jar near the bottom, then apply one knob of the discharging rod to the card, and the other to the ball of the bottle, and the discharge will pass through the card, and will make a hole through it with a burr on each side, of which I shall take more notice hereafter; it will have a strong sulphureous smell.

If the experiment be made with two cards instead of one, the cards must be placed but at a very small distance from each other; each of the cards, after the explosion, will be found pierced with one or more holes, and each hole will have burrs on both surfaces of the card.

To stain paper, you must lay a chain upon a sheet of white paper, and pass a shock through it; the paper will be found to be stained with a blackish tinge at every juncture of the links. If you make this experiment in the dark, a spark with a kind of radiation will be seen at each juncture; and the chain will appear illuminated like a line of fire; an iron chain answers best the purpose.

You may also, by the discharge, *stain glass with gold leaf*; for this end, take two slips of common window glass, each about an inch broad, and three or four inches long; then take a narrow slip of gold or silver leaf, and put it between the glasses lengthwise, letting the ends of the leaf hang half an inch without the glasses at each end; place the glasses in the small wooden press, and fix them there by a gentle pressure, and then lay them down on the table, so that one end of the metal leaf may be in contact with the coating at the bottom of the jar; and when the jar is charged, put one end of the discharging rod upon that part of the leaf that lies without the glass, which is farther from the jar, and apply the other end of the discharger to the top of the jar, and the fluid will pass through the metal leaf; and when the glasses are taken asunder, you will find, that the leaf has been actually melted by the electric lightning, and driven into the very substance of the glass.*

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* *Jones*'s Physiological Disquisitions.

A pane of glass, coated on each side, the coating being every where about two inches from the edge, with a picture pasted on the upper side, and put into a frame, is called the *magic picture*; one line of tin-foil, that goes from the coating of the under side, is made to communicate with the bottom of the frame; the back edge of the bottom rail and the frame is covered with tin-foil. Set the face of the picture against the ball of the conductor, and turn the machine. Then take it away, and holding it in an horizontal position by the top of the frame, drop a small piece of money upon the head. You may then desire any person to take hold of the lower rail of the frame with one hand, and to take off the piece of money with the other; in attempting to do this, he will fail of his design, for the moment he touches the money he will receive a strong shock. You must continue to hold the frame all the while, and will have nothing to fear, because none of the electric virtue, with which the picture is charged, can come to you, as you are not in the circuit.

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* The wooden press is generally adapted to the universal discharger, *plate* 1, *fig*. 15, the jointed balls and wires of which may be readily and conveniently applied to the extremities of the gold leaf above-mentioned. A chain or wire from the outside of the jar is to be connected with the ring of one wire, and the chain of the discharging rod with the other, before the discharge is made.
EDIT.

This bottle is called the *spotted bottle, plate* 1, *fig.* 18, because it is only coated with small pieces of tin-foil, placed at a little distance from each other; charge this bottle in the usual manner, in a darkened room, and you will see strong sparks of electricity fly from one spot of tin-foil to the other, making the passage of the fluid on the outside very visible. Discharge this bottle, by bringing a pointed wire gradually near the knob, and the uncoated part of the glass between the spots will be pleasingly illuminated, and the noise will resemble that of small fired crackers. If the jar is discharged suddenly, the outside surface appears illuminated. To produce these appearances, the glass must be very dry.

Hold a phial in the hand which has no coating on the outside, and present its knob towards an electrified conductor; the fire, while it is charging, will pass from the outside to the hand, in a pleasing manner; on the discharge, beautiful ramifications will be seen upon the uncoated part of the jar.

By setting fire to some tow in a tin house, you have a representation of that awful appearance, *a house in flames.* To make this experiment succeed, take a piece of soft tow, dry it well, and then rub, or fill it pretty well with rosin, and place it between the balls in the inside of the house; the balls should not be far asunder, nor the charge too high; connect the hook at the bottom of the house with the bottom of the jar; let the top of the jar be connected with the conductor, and when it is charged, put one ball of the jointed discharger on the conductor, and bring the other down upon the ball above the house; the explosion will set the tow on fire, whose flames will pass through the windows, and make the house appear like one on fire.

You may pleasingly illustrate the nature of the Leyden phial, by suspending two sets of bells therefrom; one set connected with the inside, the other with the outside, see *plate* 1, *fig*. 16. Hook up the chain from the bells communicating with the inside, that they may have no connexion with the table; charge the bottle in the usual manner; during the charge, the set suspended from the outside will continue to ring. After the bottle is charged, unhook the wire of the bells suspended from the inside. Touch now the wire A, and the bells will cease ringing, but the other set will begin to act; take the finger from A, and apply it to B, and the bells at B will be quiet, while those at A will be set in motion, and so on alternately, till the bottle is discharged.

EXPERIMENTS WITH THE ELECTRICAL BATTERY.

The most formidable part of the electrical apparatus is the *electrical battery*, that is, a number of jars connected together in a box; the bottom of the box is covered with tin-foil; from these a hook projects on the outside of the box, by which any substance may be connected with the outside of the jars; their insides are all connected by wires.

With a battery you may perform a great number of very surprizing and interesting experiments; and though, if very large, it be a formidable appendage to an electrical machine, and ought always to be used with caution, yet it cannot be said, that the apparatus of an electrician is complete without it; its effects in rending various bodies, in firing gunpowder, in melting wires, and in imitating all the effects of lightning, never fail to be viewed with astonisment.

There is some caution necessary in the use and management of a battery, and you should be careful never to make part of the circuit, and to prevent those that are seeing the experiments touching the battery, or approaching too near to any part of the apparatus; the quadrant electrometer, *plate* 1, *fig.* 17, should be always used with it; it is best to place it upon the ball, which unites the internal wires, but it should always be elevated two or three feet above the ball. A battery cannot be charged so high in proportion, as a single jar; the quadrant electrometer, therefore, never rises so high as 90 degrees, seldom higher than to 60 or 70 degrees, more or less, in proportion to the size of the battery, and the force of the machine. I must observe to you here, that if one jar in your battery be broke, you must remove the broken jar before the rest can be charged.

Mr. *Atwood* made, with his battery, a very curious experiment on the perforation of paper by the electric fluid; combined with those that I shall afterwards relate to you, you will find it prove, with great clearness, the existence and action of the two electric powers.

He suspended a quire of paper by a line, in the manner of a pendulum, from a convenient altitude, while quiescent in an horizontal direction perpendicular to the plane, the rods of communication not touching the paper; the phenomena were, first, the aperture mentioned in the leaves, being protruded both ways from the middle:* second, not the smallest motion was communicated to the paper from the force of the discharge.

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* The burr of the paper pointed one way on one side, and the opposite way on the other side, as if the hole had been made in the quire, by drawing two threads through it, in a contrary direction.

A quire of the thickest and strongest paper was made use of for this experiment, the height from which it was suspended sixteen feet. It is an extraordinary appearance on the hypothesis of a single electric fluid, that a force sufficient to penetrate a solid substance of great tenacity and cohesive force, should not communicate the smallest motion to the paper, when a breath of air would cause some sensible vibration in it. But the other phenomenon, *i. e.* the opposite direction in which the leaves are protruded, tends very much to strengthen the opinion of two opposite currents; indeed, when the two facts are taken together, it is scarcely possible to reconcile the hypothesis of a single power with matter of fact.

Mr. *Symmer* placed in the middle of a paper book, of the thickness of a quire, a slip of tin-foil; in another of the same thickness he put two slips of tin-foil, including the two middle leaves between them; upon passing the electric stroke through them, he found the following effects. In the first, the leaves on the side of the foil were pierced, while the foil itself remained unpierced; but at the same time he could perceive, that an impression had been made on each of its surfaces, at a small distance from each other; such impressions were still more visible on the paper, and might be traced as pointing different ways. In the second, all the leaves of the book were pierced, excepting the two holes that were between the slips of foil, and in these two, instead of holes, the two impressions in contrary directions were visible.

When a quire of paper, without any thing between the leaves, is pierced by the electrical stroke, the two powers keep in the same track, and make but one hole in their passage through the paper; not but that the power from above, or that from below, sometimes darts into the paper at two or more different points, making so many holes; but these generally unite before they go through the paper. They seem to pass each other about the middle of the quire, for there the edges are most visibly bent different ways; whereas, on the leaves near the outside, the holes very often carry more the appearance of a power issuing out, than of one darting into the paper.

When any thin metallic substance, such as gilt leaf, or tin-foil, is put between the leaves of the quire, and the whole is struck; the counteracting powers deviate from the direct track, and make their way in different lines to the metallic body, and strike it in two different points distant from one another, about one-fourth of an inch, more or less; the distance appearing to be generally less when the power is greatest; and whether they pierce or only make impressions upon it, they leave evident marks of motion from two different parts, and in two contrary directions.

When two slips of tin-foil are put into the middle of the quire, including two or more leaves between them, if the electricity be but weak, the counteracting powers only strike against the slips, but leave an impression; if the shock be stronger, one of the slips is pierced, but seldom both; and it appeared in general to Mr. *Symmer*, that the power which issued from the outside, acts with greater force, than that which proceeded from within.

To break thick pieces of glass. Place a thick piece of glass on the ivory plate of the universal discharger, *plate* 1, *fig.* 15, and a thick piece of ivory on the glass, on which a weight from one to seven pounds is to be placed; take off the balls a, b, bring the points of the wire against the edge of the glass, and pass the discharge through the wires, by connecting one of the wires with the hook of the battery, and forming a communication, when the battery is charged, from the other wire to the ball. By this operation the glass will be broken, and some part of it shivered to an impalpable powder. When the piece of glass is strong enough to resist the shock, the glass is often marked by the explosion with the most lively and beautiful colours.

Place a piece of very dry white wood between the balls of the universal discharger, the fibres of the wood to be in the same direction with the wire, pass the shock through them, and the wood will be torn to pieces; or run the points into the wood, and then pass the shock through them.

To melt wires by the electrical fluid, you ought to have a battery containing at least thirty square feet of coated surface; you may then connect the outside coating with a wire of about one-fiftieth of an inch in diameter, and from twelve to twenty-four inches in length; fasten the other end of the wire to one of the balls of the discharging rod; on making the discharge the wire will become red-hot, then melt and fall upon the floor or table in glowing globules. Sometimes the sparks are thrown to a considerable distance; if the force of the battery be very great, they will be entirely dispersed by the explosion.*

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* For a further variety of experiments, see our Author's Essay on Electricity. I am preparing a new edition of this work for the press, which will be published in the beginning of the next year, 1799, with many corrections and augmentations. EDIT.

LECTURE XLVIII.

OF LIGHTNING, AND THE USEFULNESS OF METALLIC CONDUCTORS TO DEFEND BUILDINGS FROM ITS EFFECTS.

Nothing can be more natural than to pass from the electrical battery to lightning itself, for the former seems to be more than an imitation; it is nature invested in her own attire. The light and sound accompanying these phenomena, when exhibited on the great scale of nature, are indeed so awfully sublime, that we can scarce with propriety reflect on the weakness of those, who, in ages less informed, supposed it to be the immediate minister of vengeance from an angry Deity. They are now more rationally considered, as the natural means of restoring a necessary equilibrium; the rough discords of nature productive of general harmony.

The phenomena of lightning are always surprizing, and sometimes terrible; there is no appearance in which there is more diversity, no two flashes being observed exactly similar to each other.

On a summer's evening, it may often be perceived to play among the clouds; this kind is quite inoffensive, and is not accompanied with thunder.

When the lightning is accompanied with thunder, it is well-defined, and has generally a zig-zag form; sometimes it only makes one angle like the letter V, sometimes it appears like the arc of a circle. But the most formidable and destructive form which lightning is ever known to assume, is that of balls of fire. The motion of these is very often easily perceptible to the eye, but wherever they fall, much mischief is the result of their explosion. The next to this, in its destructive effects, is the zig-zag kind; for that species, whose flashes are indistinct, and whose form cannot be easily observed, is seldom known to do much hurt. You may consider the colour of lightning as an indication of its power to do mischief, the palest and brightest flashes being the most destructive.

There seems to be a kind of omnipresent property in the zig-zag kind of lightning when near. If two persons are standing in a room, looking different ways, and a loud clap of thunder happens, accompanied with the zig-zag lightning, they will both distinctly see the flash, not only by that indistinct kind of illumination of the atmosphere, which is occasioned by fire of any kind, but the very form of the lightning itself, and every angle it makes in its course will be as distinctly perceptible, as though they had looked directly at the cloud from whence it proceeded. If a person was at that time to be looking on a book, or other object which he held in his hand, he would distinctly see the form of the lightning between him and the object. This property seems peculiar to lightning.

The effects of lightning are generally confined within a small space; and are seldom similar to those which accompany explosions of gunpowder, or of inflammable air in mines. Instances of this kind, however, have occurred; the following is one of the most remarkable of which we have any distinct account: "August 2, 1763, about six in the evening, there arose at Anderlight, about a league from Brussels, a conflict of several winds borne upon a thick fog. This conflict lasted four or five minutes, and was attended with a frightful hissing noise, which could be compared to nothing but the yellings of an infinite number of wild beasts. The cloud then opening, discovered a kind of very bright lightning, and in an instant the roofs of one side of the houses were carried off and dispersed at a distance; above 1000 large trees were broke off, some near the ground, others near the top, some torn up by the roots; and many both of the branches and tops carried to the distance of 60, 100, or 120 paces; whole coppices were laid on one side, as corn is by ordinary winds. The glass of the windows, which were most exposed, was shivered to pieces. A tent in a gentleman's garden was carried to the distance of 4000 paces; and a branch torn from a large tree, struck a girl in the forehead as she was coming into town, at the distance of 40 paces from the trunk of the tree, and killed her on the spot."

Thunder-storms will sometimes produce most violent whirlwinds, such as are by some philosophers attributed to electricity; nay, even occasion an agitation of the waters of the ocean itself; and all this too after the thunder and lightning has ceased. Of this we have the following instances:

" Great Malvern, October 16, 1761. On Wednesday last we had the most violent thunder ever known in the memory of man. At a quarter past four in the afternoon, we were surprized with a most shocking and dismal noise; 100 forges all at work at once, could scarce equal it. Upon the side of the hill, about 400 yards to the south-west, there appeared a prodigious smoke, attended with the same violent noise, as if a volcano had burst out of the hill; it soon descended, and passed on within about 100 yards of the south end of the house; it seemed to rise again in the meadow just below it, and continued its progress to the east, rising in the same manner for four different times, attended with the same dismal noise as at first; the air being filled with a nauseous and sulphureous smell; it gradually decreased till it was quite extinguished in a turnip field, about a quarter of a mile below the house; the turnip leaves, with leaves of trees, dirt, sticks, &c. filled the air, and flew higher than any of these hills. The thunder ceased before this happened, and the air soon after became calm and serene."

Lightning is in the hands of nature, what electricity is in ours; the wonders we now exhibit at pleasure are little imitations of those great effects which frighten and alarm us, they seem to depend on the same mechanism; the same properties, the zig-zag sparks, their similar action on conducting substances, the power of rending, inflaming, and dispersing in every direction the substances on which it acts with power, the giving polarity to feruginous matter, &c. all concur to shew their identity. But independent of these similarities, the thing is proved by the plainest and clearest evidence; when the atmosphere is charged with thunder clouds, we can by an electrical kite draw from it the matter of lightning, and with this matter perform every known electrical experiment.

You have seen, that the electric powers never become sensible to us, except when they are separated, and then chiefly in their passage from one body to another in opposite directions; and that an equal quantity of a different power must be conducted from the earth to the cloud to produce lightning. There must be the same reciprocal exchange of powers to occasion lightning from one cloud to another.

When two clouds, which are highly electrified with the different powers, come near together, they approach with an increasing force till they flash in exchanging powers. But as clouds are formed of distinct particles, and every particle has its share of both the electric powers, according to the equality or inequality of quantity of each power in each particle, it is more or less electrified; and on the various combinations of these powers, will arise the mode in which the clouds approach each other, and in which they exchange their different powers.

When the electrified particles are made so to approach each other, that their atmospheres are pressed off together to a great distance from the cloud, they then act nearly the same as if the cloud was one continuous body; but after the flash, those particles which have exchanged powers, and in which the two electricities are united, being no longer buoyed up by these agents, fall down in rain, hail, &c.

That these atmospheres are extended to a great distance from the cloud, appears from all experiments made both here and abroad; for in them it is plain, that an atmosphere goes up from the earth of the power which is contrary to that of the cloud, which would not take place if the atmosphere of the cloud did not reach the earth.

When one of these highly electrified clouds approaches so near to the earth as to exchange powers with it, then is the damage done to those things through which the exchange is made, which are generally those bodies that rise nearest the cloud.

Many are the observations which shew, that the atmosphere of the clouds are condensed at the time of their joining by a flash, and that the contrary electricity is then, as it were, drawn up from the earth. Thus, in Mr. *Ludolf*'s account, Phil. Trans. vol. xlvii. at every clap of thunder the electricity seemed extinct, and did not return till after the space of about 30 seconds; the threads which by their divergence indicated the electricity, approached each other suddenly, as if they had been pushed together with force. The Abbe *Nollet,* and many others, have observed similar appearances. In an observation of Abbe *Nollet,* the clap of thunder put a stop for some time to the force of the electricity; all this may be easily illustrated by our electrical apparatus. Bring two cork balls suspended by linen threads from the end of a wire, within the atmosmosphere of an electrified conductor, and they will be electrified with a power contrary to that which electrifies the conductor, receding from each other, but flying towards the conductor; take a spark from the conductor, and they immediately collapse, the electricity drawn into them from your body returning thereto.

It often happens, as before observed, that clouds electrified with the contrary powers are driven together, and the particles coming into contact, the powers are exchanged without that violent flash which usually accompanies a thunder storm. In this case, the particles generally descend in heavy showers of rain; but the exchange of powers is most complete in the middle of the united clouds, and the heaviest part of the shower is generally from the middle of the cloud.

In confirmation of this, I shall only mention one observation, though many might be produced; it was made by Mr. *Eeles* in October, 1760; the clouds were very distinct, and the showers heavy. In three different clouds he found the showers from the beginning electrified with the vitreous power; the showers from the middle of each cloud shewed no sign of electricity, and the end of each cloud was resinously electrified, the wind N. W. There was no appearance of electricity in the middle of the showers, because the electric powers are there united to each other in every drop; their atmospheres and actions were therefore insensible.

Rain, hail, and snow, often exhibit signs of being electrified, for the clouds are seldom so equally electrified with the different powers of electricity, as upon meeting to render them equal in each descending drop. In large flakes of snow, the electricity is often very evident; for when they come near a non-electric body, they are driven towards, and cling about it like an electrified feather.

It is not easy to form any idea of what some writers mean by a negative cloud, or a negative stroke. Is it a mere inanity which knocks down steeples, rends trees, tears up the earth, and kills men and cattle, &c. Can that, which is not, act?

You saw, by an experiment I lately exhibited to you, that if two electric plates, or two jars, be charged, and a communication be made from the vitreous side of one, to the resinous side of the other, no discharge will follow, unless a communication is formed between the other two surfaces at the same time.

The natural electricity in the atmosphere is frequently discharged in this manner: two clouds being electrified with opposite powers, the surfaces of the earth immediately under them are likewise electrified with powers contrary to those in the clouds above them; and the moisture of the earth forming a communication between the two contiguous charged surfaces, whenever the two clouds meet, there will follow a discharge both of the clouds and surfaces on the earth opposed to them. If the earth should be dry, and consequently afford a resistance to the union of the two electricities accumulated on or under its surface, there will follow an explosion in the earth as well as in the atmosphere, which will produce concussions and other phenomena which have frequently been observed to happen in dry seasons, particularly in those climates which are the most liable to storms of thunder and lightning.

The various cases of lightning are too numerous to be here considered, and too imperfectly known to be accurately explained. What I have said will, I hope, give some general notions of the method in which it operates, and lead you to a further investigation of the subject. You may from thence also readily account for its seemingly capricious nature; sometimes it will strike trees, high houses, &c. without touching cottages, men, or animals in the neighbourhood; while in other instances, low houses and cattle have been struck, while high trees, steeples, &c. near them have escaped.

All this is very easily accounted for, upon Mr. *Ecles*'s theory of a double curent, and the efforts in nature to restore the electrical fluid to a latent state, whenever by any means the powers thereof have been separated. Thus, in great thunder storms, there is a portion of the earth under the cloud which is electrified thereby with the contrary electricity; those objects therefore, which form the most perfect conductors between the clouds and that portion of the earth, will most probably be struck, as being the readiest way by which the two opposite powers can unite, and restore the electrical equilibrium both in the cloud and the earth, one part of the flash ascending from the earth, the other descending from the cloud.

Let us suppose a cloud, vitreously electrified, to be formed over a certain part of the earth's surface; the electric power of the cloud first separates that of the atmosphere, and while it is thus operating, the atmosphere is resinously electrified; in a little time the air becomes vitreously electrified, and then both it and the cloud act as one body. The surface of the earth then begins to be electrified, and the powers therein to be separated, and a continual effort is made by the contrary electricities to unite between the earth and the cloud. If those causes which first produced the electricity still act, the power becomes inconceivably great, and the flashes in uniting will tear every thing to pieces that resist their passage.

Mr. *Read* justly observes, that a portion of the earth may be highly electrified, and yet we may be insensible thereof, because we are involved therein; for where all things are equally involved in an electrical atmosphere, there can be no visible signs of the presence of the electric matter. Thus, if two or more persons be electrified, while standing on the same insulation, they shew no signs to each other of being electrified.* Whatever be a person's situation, whether in the house or open field, he is liable to be involved in an electric charge, whether it be stationary, or moving with the clouds. Mr. *Read* found himself so involved once in Hyde Park; the atmosphere had a menacing appearance with a heavy black cloud at no great distance; on taking his pocket electrometer out of its case, and holding it in his hand, it instantly diverged near one inch. It is not probable, that the restoration of the equilibrium, or returning stroke, as it is often called, will hurt any one, unless they are in the direct path of the flash.

I have already observed, that it is probable that the operations of the electrical matter are most universal and important in its latent and united state; and that, whenever by separation it becomes visible, there is then a general stress throughout the greater part of our system to restore the equilibrium; and that this stress is greater in proportion to the quantity separated; that this separation in many instances is spontaneous; and that as this fluid is universally disseminated, there is no occasion to consider the appearances of electricity in vapour, &c. as the means whereby this fluid is conveyed to the clouds.

From M. *de Luc*'s observations, it would hence appear, that lightning often arises from the sudden production of a great quantity of the electrical fluid, that which is then manifested, not being apparent as electricity, but just before we perceive its effects. This is further confirmed by his observations when on mountains, where he had often opportunities of viewing these phenomena. Thus, in a storm on the Buet, one of the Alps, while the air was perfectly transparent and dry (the last circumstance being determined by the hygrometer), clouds began to form in different parts; these, when thickened and united, embraced the summit of the Buet, and supported themselves against Mount Blanc, and the summits of the neighbouring mountains. M. *de Luc* and his companions were overwhelmed with rain; there was also a vast deal of lightning, which was often violent, and lasted for a considerable time. M. *de Saussure* has also given instances where the clouds formed a conducting communication with the ground, and yet the lightning continued without interruption.

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* *Read*, p. 61 and 68.

From these phenomena, air perfectly transparent and dry, containing neither the vapours of which the cloud is formed, nor the electric fluid, but only the ingredients proper to give them birth, he infers, that by some unknown cause, clouds of a certain kind are formed spontaneously, and during the progress of their formation, the electricity is produced in great abundance, exploding every time it is thus formed; and that before this, the electric fluid no more existed in that state, than the aerial fluids, which are disengaged from gunpowder, existed as such before the gunpowder was exploded. I need scarce observe to you, how much Mr. *Eeles*'s theory is confirmed by this account of M. *de Luc*.

You may gain some idea of the prodigious quantity of the electric fluid, that is sometimes manifested, and passing between the clouds and the earth, by an instance or two with which we are furnished by M. *de Luc*. Thus, a cloud was observed at the top of the mountains of Turin: it was formed of a mass, whose obscurity rendered it terrific, producing in those places, over which it was situated, night at noon day; this mass was ploughed as it were by lightning, which was soon after followed by a grumbling kind of thunder; there fell so prodigious a quantity of water and ice from this cloud, that the country was ravaged by the torrents, the hedges were beat down, and the ditches half filled with hail. Erfurt, a small city in Germany, was struck in one night in forty-two different places; seven persons were killed, three houses were set on fire, but quenched by the rain, which came down in torrents. Now where shall we find, on the vapour theory, known humidity in any strata of transparent air, sufficient to explain the formation of such clouds, and the torrents of rain which were discharged from them?

OF CONDUCTING RODS.

We are now prepared to consider the advantages of conducting rods. You know that the electrical fluid is always impelled to those places where an exchange of powers can be most easily made, or where the union of the two powers is least resisted. If then there happens, in any of the preceding instances, to be a house furnished with a conducting rod, directly between that part of the cloud and that part of the earth, where there is the greatest effort for restoring the equilibrium, the conductor will be struck, and will probably prevent the building from receiving any injury. If there be no conductor, the lightning will for the foregoing reasons pass at the same place, but the building will probably be damaged, because the materials resist the passage of the electrical powers.

OF POINTED AND KNOBBED CONDUCTORS.

A great dispute has been carried on among electricians concerning the termination of conducting rods, for preserving buildings from lightning; some warmly contending, that they should be terminated by knobs or balls; others as strenuously contending, that they should be pointed.

Ever since the identity of electricity and lightning has been proved, conductors of some kind have been generally allowed to be necessary for the safety of buildings in thunder storms, as they afford a ready passage for the union of the contrary electricities. Electricians seem to have forgot, that neither lightning nor electricity ever strike a body, merely for the sake of the body, but because that body is a means of restoring the disturbed equilibrium.

When a quantity of electricity is excited by means of an electric machine, a body communicating with the earth, will receive a strong spark from the prime conductor; it receives this spark, not because it is capable of containing all the electricity of the cylinder and conductor, but because, the natural situation of the fluid being disturbed by the motion of the machine, the natural powers make an effort to restore the equilibrium. No sooner, then, is a conducting body, communicating with the earth, presented to the prime conductor, than the whole effort of the electricity is directed against that body; not merely because it is a conductor, but because it affords a place, by which the natural powers can more readily unite, and which they would do by other means, though that body were not to be presented. That this is the case, we may easily see, by presenting the same conducting substance in an insulated state to the prime conductor of the machine, when we shall find only a small spark will be produced. In like manner, when lightning strikes a tree, a house, or a conducting rod, it is not because these objects are high, but because they are situated in that place, where, from a variety of causes, the impetus of the two powers can be lessened by uniting with each other.

From hence you will perceive the fallacy of that kind of reasoning, which is generally employed concerning the use of thunder rods.

Because a point presented to an electrified body, in our experiments, draws off the electricity in a silent manner, Dr. *Franklin* and his followers have concluded, that a pointed conductor will do the same thing to a thunder cloud, and thus prevent any kind of danger from a stroke of lightning.

But, for this very reason, Mr. *Wilson* and his party have determined, that the use of pointed conductors is utterly unsafe; they justly consider the Franklinian idea of exhausting the clouds of their electricity, to be not less absurd, than it would be to clear away an inundation with a shovel, or exhaust the atmosphere with an air-pump. They bring many instances, where a point will receive a full stroke, and assert that it solicits a discharge; and that, being often unable to conduct the whole electricity of the atmosphere, it is impossible for us to know whether the discharge they solicit may not be too great for our conductor to bear; and, consequently, all the mischiefs arising from thunder storms may be expected, with this mortifying circumstance, that this very conductor hath probably solicited the fatal stroke.

I must also further observe to you, that the Franklinians, granting them all they ask, still make their pointed conductors of too much consequence; for it is now well known, that points have no influence at all, unless they are immerged in the electrified atmosphere. If a pointed body does not communicate with the earth, but the communication is interrupted by a short interval, it will receive a full spark. It will also receive a full spark, if it be suddenly brought sufficiently near a strongly electrified body: this case applies strongly against pointed conducting rods for shipping. It will also receive a full spark at a considerable distance, if surrounded with non-conducting substances. The circumstances on which an explosion depends are too many to be here enumerated; in general it may be said that, with respect to a point, it will depend on the suddenness of the discharge, on the proximity of the cloud, on the velocity in its motion, on the quantity of electricity contained in it, and on the contrary electricity opposed to it. If a small cloud hangs suspended under a large cloud loaded with electric matter, pointed conductors on a building underneath will receive the discharge by explosion, in preference to those terminated by balls; the small cloud will form an interruption, which allows only an instant of time for the discharge. If a single electric cloud is driven with considerable velocity near to a pointed conductor, the charge may be caused to explode upon it by the motion of the charged body.

A pointed conductor has not even the power of attracting the lightning a few feet out of the direction it would choose itself: of this we have a most decisive instance in what happened to the magazine at Purfleet, in Essex. That house was furnished with a conductor, raised above the highest part of the building; nevertheless, a flash of lightning struck an iron cramp in the corner of the wall of the building, considerably lower than the top of the conductor, and only forty-six feet in a sloping line distant from the point.

The conductor, with all its power of drawing off the electric matter, was neither able to prevent the flash, nor to turn it forty-six feet out of its way.

The matter of fact is, the lightning was determined to enter the earth at the place where the Board-house stands, or near it; the conductor fixed on the house offered the easiest communication, but forty-six feet of air intervening between the point of the conductor and the place of the explosion, the resistance was less through the blunt cramp of iron and a few bricks moistened with the rain to the side of the metalline conductor, than through the forty-six feet of air to its point; for the former was the way in which the lightning actually passed.

An objection to the use of conductors of either kind may be also drawn from the accident which happened to the poor-house at Heckingham, Norfolk, which was struck by lightning, though furnished with eight pointed conductors, and which, I am well assured from good authority, were uninterrupted, continuous, and at the time of the stroke perfectly connected with the common stock. Hence it is evident, that the effect of conductors, in general, is too inconsiderable either to lessen fear or animate hope.

The *thunder house*, *plate* 2, *fig.* 3, as it is usually called, is the apparatus principally used to illustrate the Franklinian method of preserving houses from damage by lightning. It consists of a mahogany board, shaped like the gable end of a house. It is fixed upright on an horizontal board as a stand; a square hole is made in the gable board, into which is fitted, so as to go in and out easily, a square piece of wood; a wire is fixed in the one diagonal of this board, and wires are also fixed in the gable board, one from the upper part, the lower end of which comes to one corner of the square hole; the upper end of the other wire coincides with the opposite corner, and goes down to the bottom of the gable board. The upper wire has a brass ball on the top; this may be occasionally taken off, which leaves a point exposed; at the bottom of the lower wire there is a hook: connect the hook at the bottom with the outer coating of a jar, place the square piece in the hole, so that the metallic wire shall not coincide with the other two; when the jar is charged, bring the discharging rod from the knob thereof to the ball of the house; an explosion will ensue, and the square piece be driven out to a good distance from the gable board.

Put the square piece into the hole in such a manner, that the ends of the diagonal may not coincide with the ends of the wire of the gable board, then make the discharge as before, and the metallic circuit being now complete, the square board will remain in its place.*

Take off the ball, and the point will prevent an explosion, and its accumulating therein in any sufficient quantity to do any damage.

The prime conductor is supposed to represent a thunder cloud discharging its contents on some metal projection on the top of a building; and this is considered as receiving no damage when the conductor is perfect; but when the connexion is imperfect, the fluid in passing from one part to the other, damages the building.

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* If two square pieces are made and placed in the two different directions, the property is then shewn at one discharge of the jar.

In respect to the best form for conductors; from a great variety of experiments that I have made, and also been a witness to, pointed conductors have all the properties of blunt ones under all circumstances, and, moreover, some advantageous properties peculiar to their pointed terminations. Upon the whole, I recommend, and give the preference to conductors with very fine and pure metallic points. Edit.

LECTURE XLIX.

ON THE NATURE OF ELECTRICITY; OF ANIMAL ELECTRICITY, &c.

After pointing out to you the principal phenomena of electricity, and exhibiting to you many of the most interesting and entertaining experiments in this branch of natural philosophy; I shall now endeavour to trace out its connexion with the great agents in the operations of nature, and thus lead you to form some idea of what electricity is, and of its use in the great system of things. Whatever it may be, it is certain, and that without any exaggeration, that whether you look to the heaven above, or the earth beneath, you can scarce perceive any thing that is not acted upon, and in a manner perfectly subjected to the operations of this wonderful fluid.

That electricity is real matter, and not a mere property, is evident from a variety of circumstances. When it passes between bodies, it divides the air, and puts it into those undulations which give us the idea of sound. It emits the rays of light in every direction, and those rays are variously refrangible and colorific, as other light is: and, if light is acknowledged to be matter, it is contrary to reason and experience to suppose that the thing which emits it should not likewise be material; neither are the other senses unaffected at its presence: its smell is strongly phosphoreal or sulphureous. The sense of feeling is a witness of its presence, not only from the sparks which, when received from the conductor of a powerful machine, are pungent, and will pass through two or three persons standing on the ground.

but also from the shock. A stream of electric matter has also evidently a subacid taste.

In contemplating the system of nature, you perceive three kinds of fluids of extreme subtilety, and very much resembling one another: these three are, fire, light, and electricity. Their resemblance is so great, that it is not surprizing to find it the general conception of all uninformed minds, that they are ultimately the same; on examining the evidence of their identity, you will find it exceeding strong.

If it be true, that natural effects are not to be ascribed to many different means or agents, where one will suffice, these three should be considered as different modifications or states of the same fluid. Light or solar fire will burn in fuel, and act in solid matter with greater effect than the most violent fire of a furnace. Common fire, like that of the sun, will promote vegetation and ripen fruits. The electric fire will light a candle and fire gunpowder, like the common fire; will afford a spectrum of the seven primordial colours, in common with light; and will throw metals into fusion with a violent scorching heat.* Let us leave generals, and descend more into particulars.

These three fluids all agree in one property, that of exciting heat in certain circumstances, and not doing so in others.

Fire, in the common acceptation of the word, always excites heat; but in its latent state, it lays aside this property, and in vapour, for instance, is cold to the touch.

Light, when collected into a focus by a burning glass, *i. e.* when its rays converge to a center, and diverge, or attempt to diverge from one, produces heat.

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* *Jones*'s Physiological Disquisitions.

Electricity, when its force is concentrated and converged, produces heat, as I shall soon shew you by its effect on a thermometer. This does away the objection formerly made to those who asserted, that electricity was that elementary fire which pervaded all substances: the objection was, that though the electric matter emitted light, and had the appearance of fire, it wanted its essential characteristic of burning; and where great quantities of the fluid were forced through substances, they insinuated, that it might be occasioned by the internal commotion excited among their small particles.

There is no occasion to dwell upon the weakness and fallacy of the objection, as it is completely removed by many facts. 1. The effect of electricity upon the thermometer. 2. By the experiment that was made at the Pantheon by Mr. *Wilson*, with the immense apparatus that was constructed for making experiments on the preferable utility of pointed or knobbed conductors, for preserving buildings from lightning. The electric aura from this machine fired gunpowder in the most unfavourable circumstances that can be imagined, namely, when it was drawn off by a sharp point, in which case it has generally the least force. Upon a staff of baked wood a stem of brass was fixed, which terminated at the top in a wooden point; this point was put into the end of a small tube of Indian paper, made somewhat in form of a cartridge, about an inch and a quarter long, and $\frac{2}{10}$ths of an inch in diameter. When the cartridge was filled with common gunpowder unbruised, a wire communicating with the earth was fastened to the bottom of the brass stem. The charge in the large conductor being kept up by the motion of the cylinder, the top of the cartridge was brought near to the conductor, so as even frequently to touch the tin-foil with which it was covered. In this situation, a small faint luminous stream was frequently observed between the top of the cartridge and the metal. Sometimes this stream would set fire to the gun-powder the moment it was applied; at others, it would require half a minute or more, before it would take effect. The difference in time was supposed to arise from some moisture in the powder. Tinder was fired much more readily.

It now appears clearly, that the electric fluid moving through bodies, either in small quantities, or with rapidity, or in very great quantities, will produce heat, and set them on fire: it seems therefore scarce disputable, that this fluid is the same with the element of fire.

These are far from being the only instances of their identity; for fire is brought into action by friction, as well as electricity. Fire dilates all bodies: the electric fluid has also a dilating power, which is evident from its action on a thermometer, though, in general, the force with which bodies cohere together is greater than the dilating power of electricity.

Fire promotes and accelerates vegetation as well as germination. Electricity does the same.

Electricity, as well as fire, accelerates evaporation.

The experiments made by Mr. *Achard* on the eggs of a hen, and by others on the eggs of moths, prove that electricity, as well as heat, favours the developement of those animals. The electric fluid, in common with fire, will throw metals into fusion.

If substances with equal degrees of heat touch each other, the heat is diffused uniformly between them. In the same manner, if two bodies with unequal degrees, or different kinds of electricity, touch each other, an equilibrium will be established.

If bodies of different kinds, and of equal degrees of heat, are placed in a medium of a different temperature, they will all acquire, at the end of a certain time, the same degree of heat. There is a considerable difference, however, in the space of time in which they acquire the temperature of the medium: *ex. gr.* metals take less time than glass to acquire or lose an equal degree of heat.

On an attentive examination of the bodies which receive and lose their heat soonest, when they are placed in mediums of different temperatures, they will be found to be the same which receive and lose the electric signs soonest. Metals, which become warm or grow cool the quickest, are the substances in which the electric powers unite most readily. Wood, which requires more time to be heated or cooled, receives and loses electricity slower than metals. Lastly, glass and resinous substances, which receive and lose slowly the electric fluid, acquire with difficulty the temperature of the medium which surrounds them.

If one extremity of an iron rod be heated red-hot, the other extremity, though the bar is several feet long, will become so warm in a little time, that the hand cannot hold it, because the iron conducts fire readily; but a tube of glass, only a few inches long, may be held in the hand, even while the other end is melting. The electric fluid, in the same manner, passes with great velocity from one end of a rod of iron to the other; but it is a considerable time before a tube of glass, at one end of which an excited electric is held, will give electric signs at the other.

These observations prove, that several bodies that receive and lose with difficulty their actual degree of heat, receive and lose also with difficulty their electricity.

The electric powers may be put in action by heat and cold. Mr. *Canton* procured some thin glass balls, of about an inch and an half in diameter, with stems or tubes about eight or nine inches in length, and electrified them, some vitreously on the inside, others resinously, and then sealed them hermetically; soon after he applied the naked balls to his electrometer, and could not observe the least sign of their being electrical; but holding them at the fire, at the distance of five or six inches, they became strongly electrical in a short time, and more so when they were cooling. These balls would, every time they were heated, give the electric power to, or take it from other bodies, according to the vitreous or resinous state of it within them. Heating them frequently diminished their power, but keeping one of them under water a week did not in the least impair it. The balls retained their virtue above six years.

The tourmalin, and many other precious stones, are also known to acquire electricity by heat. The tourmalin has always at the same time a vitreous and resinous electricity; one side of it being in one state, the other in the opposite. Sometimes one side will at the same time possess both electricities. These powers may be excited by friction and by heat; nay, even by plunging it in boiling water.

Many instances prove, that electricity is produced by liquifaction. Thus, where chocolate is manufactured in large quantities, a vivid light is frequently seen flashing upon its surface after melting, and it will also attract light substances, separate pith balls, &c. When it had lost this property, Mr. *Henly* found it might be restored by melting it together with a small quantity of olive-oil. If sulphur be melted in a glass vessel, and taken out when cool, both it and the glass will be found strongly electrified.

I have already shewn you, that electricity is produced by the evaporation of water; I shall now relate Mr. *Read*'s * mode of performing this experiment. He insulates a large hollow tin cone, containing about four sheets of tin plates, with many yards of small wires coiled up within it; one end of the wire is extended from the cone to a very sensible electrometer. The cone and wire collect and condense the ascending electrified vapour, as it quits the insulated vessel containing the fluid. The electrometer connected with the cone is vitreously electrified; that connected with the vessel from whence the vapour arose, is in a resinous state.

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* *Read*'s Summary View of Spontaneous Electricity, &c.

Mr. *Read* has also, by burning different substances in insulated vessels under his tin cone, shewn that bodies, in passing from a solid to a fluid state, produce the two electricities; the quantity observed is in general very small, on account of the intimate affinity between flame and electricity.

ACTION OF ELECTRICITY ON A THERMOMETER.

Insulate a sensible mercurial thermometer, and place the bulb between two balls of wood, one affixed to the conductor, the other communicating with the ground; and the electric fluid, in passing between the two balls, will raise the mercury in the thermometer considerably. With a cylinder of about seven inches and a half in diameter, the fluid passing from a ball of lignum vitæ to a ball of beech, and thence to the ground, elevated the quicksilver in the thermometer from 68° to 110°, repeatedly to 105°. The thermometer was raised from 68° to 85°, by the fluid passing from a point of box to a point of lignum vitæ; from 67° to 100° from a point of box to a ball of box; from 66° to 100° from a ball of box to a brass point; from 69° to 100° from ball to ball; the bulb of the thermometer being covered with flannel.

" If then these fluids, fire, light, and electricity, which thus mutually and in all respects assume each others properties, are not the same; experiment is a thing not to be depended upon, and the most obvious rules of philosophizing, adopted and approved by all parties, are no better than specious deceptions."

More, indeed, need not be said to any observer of nature; but it is necessary to accumulate proof, in order to lessen the prejudices of modern philosophers, who have altogether neglected to study and trace the great agents of nature. For these, it may be necessary to point out other links, in which they may see the connexion between fire, light, and electricity.

Thus, as heat is diminished, or bodies are cooled, electricity succeeds in its place. All electric bodies by heat are rendered conductors, and can no longer be excited; but, as soon as the heat is removed, their electric property returns.

Water is a conducting substance: by being frozen, its conducting powers are lessened; when cooled down to twenty degrees below 0 of *Fahrenheit's* scale, it becomes an electric, and will emit sparks by friction, like glass. The atmosphere is a natural electric; but, by a certain degree of heat, it loses in a degree this property, and becomes a conductor; nor is there any doubt that its electric properties are increased, in proportion to the degree of cold imparted to it.

Mr. *Æpinus* mentions some facts in a letter to Dr. *Guthrie*, which will illustrate this subject; they relate to phenomena that are known to take place in Russia, when a great cold has continued for several weeks. Mr. *Æpinus* was sent for, to see an uncommon phenomenon. On going into the apartment of Prince *Orloff*, he found him at his toilet, and that at every time his valet drew his comb through his hair, a pretty strong crackling noise was heard; and on darkning the room, the sparks were seen following the comb in great abundance, while the Prince was so completely electrified, that strong sparks could be drawn from his hands and face; nay, he was even electrified, when he was only powdered with a puff.

A few days after, Mr. *Æpinus* was witness to a more striking effect of the electric state of a Russian atmosphere. The Great Duke of Russia sent for him one evening in the twilight, and told him, that having briskly drawn a flannel cover off a green damask chair in his bed-chamber, he was astonished at the appearance of a strong bright flame that followed; but, considering it as an electrical appearance, he had tried to produce a similar illumination on different pieces of furniture, and could then shew him a beautiful and surprizing experiment. His Highness threw himself on his bed, which was covered with a damask quilt, laced with gold, and rubbing it with his hands in all directions, the young Prince, who had then reached his twelfth year, appeared to be swimming in fire, as at every stroke flames arose all around him, darted to the gold-lace border, ran along it, and up to that of the bed, and even to the very top.

While his Highness was shewing this experiment, Prince *Orloff* came into the room with a sable muff in his hand, and shewed us, that by only whirling it five or six times round his head in the air, he could electrify himself so strongly, as to send out sparks from all the uncovered parts of his body. The inlaid floors had become so dry, as to form a complete insulation.

In the winter time, therefore, we must consider the frozen surface of the earth, the water, and atmosphere, as forming one electrical machine of enormous magnitude; for, the natural cold of those countries is often cold enough to cool water to more than 20 degrees below 0, and thus render it an electric. That something of this kind is real, appears from the excessive bright aurora borealis, and other electric appearances, far exceeding any thing in this country. In the summer time these appearances are not remarkable, but an excessive heat prevails from the long continuance of the sun above the horizon. The quantity of heat in summer being succeeded by a proportionable quantity of electricity in winter, one can scarce avoid concluding, that the heat in summer, or disengaged fire, becomes electric fluid in winter, which going off through the celestial expanse, returns again to the grand source of light and heat; thus making room for the succeeding quantities which are to enliven the earth during the following season.

If the identity of light, fire, and electricity, be admitted, the source from whence the electric fluid is derived into the earth and atmosphere is very evident; it can be no other than the sun or source of light. The vast quantity of light continually proceeding from the sun to the earth, must in a great measure be absorbed thereby; but, from the other operations in nature, it is prevented from remaining there: it is therefore in continual circulation, to make room for new quantities continually coming from the sun. It must however be observed, that as this fluid is variously combined, it cannot appear in its natural form of fire or light, till it is disengaged, and capable of receiving a motion similar to what it had when proceeding from the sun.

This change of matter into a different form, with the subsequent regeneration of it into its primitive form, is, says Mr. *Jones*, one of the great secrets of nature, whereby the world is kept from decaying, either with respect to its matter or its motion. By means of a circulation in matter, the lasting motions of nature are maintained, and its stores unexhausted.*

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* See Jones's Physiological Disquisitions, p. 51.

The experiments that I shall now lay before you, do in the strongest manner prove the identity of the electric fluid and light, and that both are transmitted through electric as well as other substances; and that it is on the motion of this fluid that transparency depends; that, when this medium is at rest, the body is opake; when set in motion, it becomes transparent.

LUMINOUS EXPERIMENTS.

To render an ivory ball luminous. Take a strong spark through the center of the ball, and it will be illuminated throughout.

To obtain a crimson coloured spark. Take a spark through a ball of box wood, and it will appear of a beautiful crimson, or rather a fine scarlet colour; or the shock may be passed through pieces of wood of different thicknesses and density; which will afford a very ample field for observation and experiment.

To make a bottle of water luminous. Connect one end of a chain with the outside of a charged jar, let the other end lie on the table, place the end of another piece of chain at about one quarter of an inch distance from the former; then set a decanter of water on these separated ends, and, on making the discharge through the chain, the water will appear perfectly and beautifully luminous.

There is scarce any substance, fluid or solid, but what may be rendered luminous, by passing the electric fluid through it, and thereby separating the electric powers inherent in the body. In water, spirit, oil, animal fluids of all kinds, the discharge of a Leyden phial of almost any size will appear very splendid, provided you take care to place them in the circuit, so that the fluid may not pass through too great a quantity of them.

To perform this, place the fluid, on which the experiment is to be made, in a tube three quarters of an inch in diameter and four inches long; stop up the orifices of the tube with two corks, through which push two pointed wires, so that the points may approach within one-eighth of an inch to each other; the fluid, in passing through the interval which separates the wires, is always luminous, if a force be used sufficiently strong; the glass tube, if not very thick, always breaks when this experiment succeeds.

To make the passage of the fluid luminous in the acids, they must be placed in capillary tubes, and two wires introduced, as in the preceding experiment, whose points shall be very near each other. It is a well-known fact, that the discharge of a small Leyden phial, in passing over a strip of gold, silver, or Dutch metal leaf, will appear very luminous. By conveying the contents of a jar, measuring two gallons, over a strip of gold-leaf one-eighth of an inch in diameter and a yard long, it will frequently give the whole a dazzling brightness. You may give this experiment a curious diversity, by laying the gold or silver leaf on a piece of glass, and then placing the glass in water; for, the whole gold leaf will appear most brilliantly luminous in the water, by exposing it thus circumstanced to the explosion of a battery.

The difficulty of making any quantity of the electrical fluid luminous in any body, increases as the conducting power of that body increases; because the two powers unite sooner in proportion to the conducting power, and consequently all electric signs vanish.

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* See Mr. *Morgan's* paper, Phil. Trans.

In order to make the contents of a jar luminous in boiling water, a much higher charge is necessary, than would be sufficient to make it luminous in cold water, which is universally allowed to be the worst conductor.

There are various reasons for believing the acids to be very good conductors; if, therefore, into a tube filled with water and circumstanced as has been already described, a few drops of either of the mineral acids are poured, it will be almost impossible to make the fluid luminous in its passage through the tube, as the two powers unite immediately.

The ease with which the electrical fluid is rendered luminous in any particular body, is increased by increasing the rarity of the body. The appearance of a spark, or of the discharge of a Leyden phial, in rarefied air is well known. But we need not rest the truth of the preceding observation on the several varieties of this fact; similar phenomena attend the rarefaction of ether, of spirits of wine, and of water.

Spark in rarefied water, spirit of wine, ether, and acids. Into the orifice of a tube forty-eight inches long and two-thirds of an inch in diameter, Mr. *Morgan* cemented an iron ball, so as to bear the weight which presses upon it when the tube is filled with quicksilver, leaving only an interval at the open end, which contains a few drops of water. Having inverted the tube, and plunged the open end of it into a bason of mercury, the mercury in the tube stood nearly half an inch lower than it did in a barometer at the same instant, owing to the vapour which was formed by the water. But through this rarefied water, the electrical spark passed as luminously as it does through air equally rarefied.

If, instead of water, a few drops of spirits of wine are placed on the surface of the mercury, phenomena, similar to those of the preceding experiment, will be discovered, with this difference only, that as the vapour in this case is more dense, the electrical spark, in its passage through it, is not quite so luminous as it is in the vapour of water.

Good ether, substituted in the room of the spirits of wine, will press the mercury down so low as the height of 16 or 17 inches. The electrical fluid, in passing through this vapour, unless the force be very great indeed, is scarcely luminous; but if the pressure on the surface of the mercury in the bason, be gradually lessened by the aid of an air-pump, the vapour will become more and more rare, and the electric spark, in passing through it, more and more luminous.

The brilliancy and splendor of the electric spark is always increased when it is compressed into a smaller compass. That is, a spark, or the discharge of a battery, which we might suppose equal to a sphere one quarter of an inch in diameter, will appear much more brilliant, if the same quantity of fluid is compressed into a sphere one-eighth of an inch in diameter. This observation is the obvious consequence of many known facts; if the machine be large enough to afford a spark, whose length is nine or ten inches, this spark may be seen sometimes forming itself into a brush, in which state it occupies more room, but apppears very faintly luminous; at other times, the same spark is seen dividing itself into a variety of ramifications, which shoot into the surrounding air. In this case, likewise, the fluid is diffused over a large surface, and in proportion to the diffusion, so is the faintness of the appearance. A spark, which in the open air cannot exceed one quarter of an inch in diameter, will appear to fill the whole of an exhausted receiver, four inches wide and eight inches long: but in the former case it is brilliant, and in the latter it grows fainter and fainter, as the size of the receiver increases.

This observation is further proved by the following experiments.

Introduce two pointed wires into the vacuum, so that the point may easily pass from the point of the one to the point of the other; when the distance between them is not more than the one-tenth of an inch, in this case we shall find a brilliancy as great as in the open air.

Into a Torricellian vacuum, thirty-six inches long convey as much air as will fill two inches only of the exhausted tube if it were inverted in water; this quantity of air will afford resistance enough to condense the fluid, as it passes through the tube into a spark thirty-eight inches in length. The brilliancy of the spark in condensed air, in water, and in all substances through which it passes with difficulty, depends on principles similar to those which account for the preceding facts.

In the appearances of electricity, as well as in those of burning bodies, there are cases in which all the rays of light do not escape; and the most refrangible rays are those which escape first or most easily. The electrical brush is always of a purple or bluish hue. If you convey a spark through a Torricellian vacuum, made without boiling the mercury in the tube, the brush will display the indigo rays.

To an insulated metallic ball, four inches in diameter, fix a wire a foot and a half long; this wire should terminate in four ramifications, each of which must be fixed to a metallic ball half an inch in diameter, and placed at an equal distance from a metallic plate, which must be communicated by metallic conductors with the ground. A powerful spark, after falling on the large ball at one extremity of the wire, will be divided in its passage from the four small balls to the metallic plate. When you examine the division of the fluid in a darkened room, you will discover some little ramifications, which will yield the indigo rays only: indeed, at the edges of all weak sparks, the same purple appearance may be discovered. You may likewise observe, that the nearer you approach the center of the spark, the greater is the brilliancy of its colour.

The influence of different media on electrical light is analogous to their influence on solar light, and will help us to account for some very singular appearances.

Let a pointed wire, having a metallic ball fixed to one end of its extremities, be forced obliquely into a piece of wood, so as to make a small angle with the surface of the wood, and to make the point lie about one eighth of an inch below the surface. Let another pointed wire, which communicates with the ground, be forced in the same manner into the same wood, so that its point likewise may lie about one-eighth of an inch below the surface, and about two inches distant from the point of the first wire. Let the wood be insulated, and a strong spark, which strikes on the metallic ball, will force its passage through the interval of wood which lies between the points, and appear as red as blood. To prove that this appearance depends on the wood's absorption of all the rays but the red; when these points were deepest below the surface, the red only came to the eye through a prism; when they were raised a little nearer the surface, the red and orange appeared; when nearer still, the yellow; and so on, till, by making the spark pass through the wood very near its surface, all the rays were at length able to reach the eye.

" Previous to the discoveries that have been made in modern times, relative to the chemical effects of light, some mathematical philosophers disputed its existence as a particular fluid, and even that of fire itself; they crudely imagined, that the phenomena of light and heat were only particular modifications of the substances, in which they appeared; a kind of vibration of their particles, transmitted by means of a medium, as in the case of sounds."

"They applied the mathematics to this hypothesis, in order to explain some particular phenomena; and as every thing that appears to be deduced from mathematical theorems easily seduces those who do not apply themselves to examine data, this theory, which effectually barred the road to the most important physical researches, met with many partizans: but chemistry and meteorology have now come in to terminate the controversy; and there are at present very few philosophers who do not agree, that lucidity and heat are the effects of two fluids, namely light and fire, which produce those particular phenomena whenever they are at liberty; but which, at the same time, may be so combined with other substances as to lie hidden in them without producing these effects, till again set at liberty. By an attention to these great agents, the study of nature has proceeded with rapidity, and the present æra will probably on this account be as much celebrated in the history of science, as those in which *Pascal* demonstrated the pressure of the air on bodies, and in which *Newton* discovered the principle of gravity.

"Our progress in the knowledge of the origin of bodies, has been much advanced in this age, since chemists and philosophers have begun to examine their volatile products, in other words, the elastic fluids; but this would have been doing but little, had not the advances in other branches of natural knowledge led them to discover, that the phenomenon of heat proceeded from a particular substance susceptible of chemical affinities, namely, fire, the immediate cause of heat. Here is then a substance of the highest importance in the composition of bodies, which nevertheless escaped the attention of philosophers, while they only estimated and expressed the amount of their products by their weights. Is it possible for any one to suppose, that we have hereby discovered all the imponderable substances that enter into the composition of natural bodies?"

Ought we to neglect the phenomena of lucidity, while every thing announces to us, that light is a chemical substance? This neglect is scarcely now to be apprehended, as philosophers are aware, that great chemical effects may be produced by imponderable substances. The phosphoric phenomena of certain mineral substances indicate clearly, that light enters as an ingredient in their composition. *Wilson* and *Beccaria* have shewn, that every substance in nature is more or less phosphorical; and you have just seen, that there is scarce any substance but what you may render luminous by separating its electric powers.

The relation of these two imponderable substances, whose existence is now established beyond a doubt, is such as in many other instances is found to subsist between such substances as enter into the composition the one of the other. Light frequently does not sensibly act otherwise than as the cause of lucidity, or of luminous phenomena; and fire in the same manner, only as the cause of heat: but at other times fire, in producing heat, produces also in the end its luminous effects; and in some circumstances light, in making visible the objects, by its reflexion contributes to produce heat. These phenomena clearly indicate, that one of these substances contains the other, but that under certain circumstances it may be so decomposed, as to permit either of them to exercise its own peculiar properties.

The most excellent *Boerhaave*, in his analysis of fire, has so clearly established the universality and importance of this element, and so stripped it of the mystic dress, in which it was enveloped before his time, that one would have imagined it scarce possible for philosophers to have resolved so many of its subtile effects to occult or fanciful properties; yet, that such has been the case is evident from the slightest inspection of modern theories. Again, though the most obvious phenomena in nature, and numerous experiments, tend to ascertain beyond all doubt, that the matter of common light or fire pervades all nature, and fills all things; yet, as I have before observed, the whole has been overlooked as an accidental filtration that implied no consequences, nor interfered with the various unintelligible properties of bodies, notwithstanding its access to their innermost penetralia.

It is evident, that the natural omnipotence of light depends on the sun; by him in a natural sense the matter of fire, as his issue, is omnipresent and all-sufficient. If the life of all things depends on the activity he communicates to them, is it not probable, that it is the influence of the solar fluid that generates and maintains that life in all its specific characters, in every being according to its kind? And that life, whether it be vegetable or animal, is such as it is according to the state of the fire in it; and that every dead thing is only so, because its fire is quenched? The ancient philosophers affirmed, that the light of the sun, which gave life and motion to all things, must be in all things; they therefore conceived all things to be replete with this fluid.

Is it not highly probable then,* that this terraqueous globe is only an accumulation of materials introduced in the boundless ocean of solar fluid for a theatre, on which, under the direction and guidance of Almighty God, it may display its inexhaustible energy and powers; the terrestrial mass being so disposed and arranged by its Divine Author, as to become a seminal bed of materials, where light and fire may pierce, animate, and display an endless variety and succession of beings? This fluid extricates all the forms, and generates all the powers of nature, out of the materials provided for it to possess.

It is impossible to form any clear or distinct idea of the agency of the solar fluid in the air, in animals, in vegetables, &c. without considering it first more in general; nor can you properly have a view of the universal agency of the element productive of fire, light, and electricity, and its importance to the animal frame, unless you take an enlarged prospect of its action. Besides, knowledge often makes more rapid advances by reasoning upon known facts than by discovering new ones, which, by their novelty, too often lead to hasty undigested theories. In the disquisition upon these fluids, I have always an eye upon the doctrine of electricity; and the preceding as well as following experiments all concur in shewing the analogy that runs through nature; and you will find that electricity, though not in name, has been the doctrine of all ages. I shall therefore continue to treat of these wonderful fluids. Of all that are known in the universe, the mobility of the matter of light is the greatest. There is not the smallest speck of colour in the beams of the sun, that does not obediently receive perpetual impressions from him in all lineal directions, by night as well as by day. The sun, as the fountain of motion, is also continually agitating this fluid either radially or obliquely, by the lateral shocks and friction of the radii upon those parts of the fluid that lie out of the line of the sun's irradiation; these, together with the constant vicissitudes of day and night, preserve a constant motion in all its internal parts.

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* See vol. ii. Lecture xxi. p. 467.

But even this is inadequate to convey to you a just idea of the constant, positive, intense energy, from the activity of the matter of light. Of this you will form a better idea, by examining the mode of its action in the interior parts of the most rigid and solid bodies. For in the most secret recesses of the most solid and passive substances, the matter of light is so far from existing in an indolent quiescent state, that it is impossible to form an adequate idea of its incessant and active energy under these circumstances. Yet this state of bodies is but little thought of by philosophers in their researches into its properties, either common or special; which I shall illustrate by considering the cases of sonorous bodies, and the phenomenon of hammering cold iron red-hot.

If this fluid resided within bodies in an indolent and passive state, it could exert no reluctation on any mechanical force, disturbing its passive occupation within bodies; whereas, in fact, its natural state is never disturbed without an active irritation being excited in the fluid, to recover and repossess its organical and interstitial inherency, greater than that by which it was expelled; it returns with a force not barely sufficient to recover the dimensions it occupied within bodies, but with a violence capable of expanding them as much beyond their natural size as the external blow or concussion tended to compress them within it: hence a vibratory colluctation takes place between that action which preserves bodies in their natural crasis, and the rapid returns of the fluid to its natural state; these vibrations continue for a time, and die away imperceptibly.

This intense agitation, excited by the collision of bodies, is not confined to their points of contact, but pervades their whole substance, and oscillates in every part. This is demonstrated to the eye and ear, when a musical chord is struck. You have specimens also of it in all elastic sonorous bodies. When a bell is struck, the sound continues labouring in the ear for a considerable time afterwards; nor is the tumult subsided when our sense of it fails; it passes through a gradual decay below the standard of sense.

Suspend an iron poker from the head, by the teeth, and the iron discovers no great degree of any sonorous quality; yet if it be struck, you will have a very striking sensation of the vibratory motion its whole substance conceives from the stroke, by the teeth's transmission of their feeling to the ear.

Physicians talk of the irritability of our nervous system, as a very misterious and wonderful phenomenon; but there are more striking examples of this irratibility in the most rigid dead substances. Substances, such as glass, bell-metal, &c. which are so rigid that few instruments will make an impression on them, yet are capable of being agitated through every atom of their substance; nay, in some cases, to be burst in pieces by the impression of certain sounds. A wine glass will burst in pieces by the action excited through its substance by certain tones of voice: columns of marble or porphyry are tremulous to thunder explosions, and certain tones of an organ.

This excessive mobility of parts throughout the whole substance of the most rigid bodies, clearly implies a great turgency of their substance with some very active fluid, so that a small increase of its action is ready to burst them in pieces. A slight resistance to the internal agitation of a bell will cause it to crack.

Now it is impossible to conceive, that such a tremulous motion should be produced through the whole continuity of such hard bodies, unless they contained in themselves some inconceivably active element, exerting a constant nisus to force their parts to as great a distance from each other as possible, and barely counteracted by the power that maintains their cohesion.

The symptoms of this restless activity within solid bodies are not confined to such as are commonly called elastic. Thus iron yields more striking proofs of this latent active principle, than any substance of greater elasticity than itself, and thus discloses to our sensible conviction precisely what that principle or restless element is, that exerts its energy so powerfully within all terrestrial bodies.

For the power within bodies, that sustains and preserves their form, is not a passive power. It is positive re-action to the approach of the parts of the body. The law of re-action, being equal to action, resides ultimately in the constitution of this powerful fluid medium. Whenever the spaces it occupies within the surfaces of bodies are pressed nearer one another by any sudden shock or collision, and consequently this medium be for an instant driven out, the next instant it returns with violence, not enough to regain its place in the body, but equal to that with which it was ejected; and therefore, in returning, it dilates its spaces as much beyond their sizes, as they were compressed below their natural standard by their collision; by which means, a temporary oscillation is excited between the efforts of that power, which circumscribes bodies, and binds them to their natural sizes, and the internal medium, which was irritated by the stroke, to act with a force equal thereto.

If the strokes, which dispossess this fluid of the spaces it naturally obtains within bodies, are quickly and successively renewed, before the colluctations raised by former ones have subsided, the internal agitation may thereby soon be raised to such a height, as to break forth and manifest itself in the form of actual fire.

Every material being through all the forms of nature, is a composition of this celestial fluid and terrestrial matter; you will find the distribution of material substances into these two classes to be the real key to all natural knowledge; it not only distinguishes this globe from the celestial fluid in which its swims, but it is to be applied to every individual terrestrial substance; which must be considered, if you would comprehend the phenomena of nature, as an intimate composition of these two elements; the latter being the organ or case to the energy of the former, and the modifier of its incessant activities, while the former is the medium used by mind to impress those characters on the latter, which are known as the distinguishing properties of different bodies.

This fluid, according to the variety of the phenomena by which its energy has been discovered to us, has been called under different circumstances *light*, *fire*, *electricity*, *materia subtilis*, *materia media*, &c. At other times it has been divested of its materiality, and has been considered merely as a principle annexed to or inherent in matter, under the terms of *occult quality*, *nisus*, *attraction*, *electric attraction*, *elasticity*, *irritability*, *stimulus*, *sympathy*, *vital principle*, *life*, &c. &c.

This invisible fire is ever ready to exert and shew itself in its effects, cherishing, heating, fermenting, dissolving, shining, and operating in the various manners, according to the subjects which employ and determine its force. It is present in all parts of the earth and firmament, though in most cases latent and unobserved, till some occasion produces it in act, and renders its effects visible; it exists in our constitution, and indeed in every form in nature in two modes, interstitially and organically. If the pores of gold, which is one of the densest known substances, exceed its solid or earthly parts, how much greater must the proportion of solar fluid be in our frame than in that of gold! To illustrate this I shall refer to the element of water.

Now water, by its transparency, certifies to your senses, that light has free access into and through its substance; and that it probably fills up its interstices, as water does a spunge when soaked in it. But we know further, by the fluidity and the volatilization of water, that the matter or light of fire has not only access to its interstices, but penetrates and occupies its similar elementary particles; for these particles could not be rendered volatile, but by internal dilatation, nor could they be dilated, but by something that reached their internal parts.

These particles then are the organical parts of water, which have their individuality as separable elementary parts, as well as their similarity of character, preserved by that etherial principle that possesses them.

These points being cleared, you will now have an obvious solution of the difficulties which have attended the question, What is the principle of natural life? Modern physiology has indeed bewildered the conception of its pupils, by not distinguishing between the term *life*, used metaphysically for our system of consciousness, or as the result of our whole composition explicable only by the Creator, and the same term *life*, used physically to denote the natural power that presides in reciprocally regulating, and being regulated by the mechanism and disposition of the whole, and every part and particle of our corporeal frame.

It is by the unremitting reciprocal corruscations of this vital principle in the fluids and solids, according to the different qualities and consistencies they assume in different parts of our constitution, that the whole system of life is displayed and maintained in every individual. Light is not more instantaneously dispatched by reflexion from a mirror, or by that power which every point of the air has of reflecting lightning, than that with which the same fluid, under the character and modification of the vital principle, acts from place to place in the human frame.

For the moment of willing, and moving any member, is undistinguishably the same; so likewise the moment of being touched, and the touch being felt. But these instantaneous transmissions in our frame are not confined to such as we have a conscious perception of; they are incessantly transacting; the remotest vibrating artery corresponding with the heart, does not more immediately and constantly feel its power, than the material principle of vitality through its whole form in our structure feels the permanent influence of its own power concentered in and irradiating from the brain, the nerves being the directors of the various intended energy of the powers of natural life. This vivifying plenum, occupying and organizing every particle and interstice in our composition, can discharge its whole nisus according to the intimation and direction of any nerve or nerves; as instantly as electricity does through the substance of the body that receives the shock.

When you consider the rarefying and expansive force of this element, which is capable in an instant of time to produce the greatest and most stupendous effects, you have a full proof not only of the power of fire, but also of the wisdom with which it is managed, and withheld from bursting forth to the utter ravage and destruction of all things; and it is very remarkable, that this same element, so fierce and destructive, should yet be so variously tempered, and applied by Divine Providence, as to be the genial and cherishing flame of all natural life.

So bright and lively are the signatures of a Divine Mind operating and displaying itself in fire and light throughout the world, that, as *Aristotle* observes, " all things seem full of divinities, whose apparitions on all sides strike and dazzle our eyes." And indeed the wisest men of antiquity, how much soever they attributed to second causes, and the force of fire, yet supposed it always to be governed by a mind or intellect active and provident, restraining its force, and directing its operations.

The order and course of things, together with what we daily experience, fully proves that there is a Mind that governs and actuates this mundane system, as the proper real agent and cause, and that the inferior instrumental cause is pure ether, fire, or the substance of light, which is applied and determined by an Infinite Mind in the macrocosm or universe with unlimited power, and according to stated rules, as it is in the microcosm, with limited power and skill by the human mind. There is no proof from reason, or experiment, of any other agent or efficient cause than mind or spirit. When I speak therefore of corporeal agents, or corporeal causes, you understand them as used in a different, subordinate, and improper sense.

The principles whereof a thing is compounded, the instrument used in its production, and the end for which it was designed, are all in vulgar use termed causes, though none of them be, strictly speaking, agent or efficient. Therefore when I speak of the element of fire as acting, it is to be understood only as a mean or instrument, which is indeed the case of all mechanical causes whatsoever. They are nevertheless sometimes termed agents, or causes, although by no means active in a strict and proper signification: when therefore force, power, virtue, or action, are mentioned as subsisting in an extended, corporeal, or mechanical being, these terms are not to be taken in a true, genuine, real, but only in a gross and popular sense, which sticks in appearances, and does not analyze things to their first principles. In compliance with established language, and the use of the world, we must employ the current phrases; but for the sake of truth, we should distinguish their meaning.*

What I have here, as well as in my former Lectures, laid before you, concur in proving (nay, all nature gives testimony thereto), " that the fluid etherial matter of the heavens acts by impulse on the solid matter of the earth; is instrumental in every one of its productions, and necessary to all the stated phenomena of nature. The elements may then be divided into active and passive; not that they are such by any inherent or essential difference, but that according to the order established by the Divine Architect, they are observed to subsist under such relations."†

OF ANIMAL ELECTRICITY.

I shall here introduce you to the reasons and experiments, which induced Dr. *Shebbeare* to adopt electricity, as the principle of vital heat and motion, in 1755; and then shew how far his opinion has been confirmed by subsequent information.

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* Siris, No. 154, 155.

† *Jones*'s Essay on the First Principles of Philosophy, p. 8.

A muscle put in motion by the will, may yet be more actuated by a farther extension of volition, as from walking to running; by this operation of the mind, there is more of the vital fire determined to the muscles employed in those actions; muscles are also brought into action by the fire from the electric machine, and palsied limbs have been rendered plump by the same machine, and a power of motion and action restored to those whose palsies have not been of long standing, and which do not take their source from the spinal marrow. This offers a convincing proof, that vital fire is the cause of muscular motion, and that the vital fire is of the same kind with that produced by our electrical machines.

After so many experiments on the electrical fluid, and after the discovery of so many phenomena, which are no ways to be distinguished from those of fire, it will scarce be any longer disputed, that they are the same in their own nature. Nor will any one, I presume, after the fire put in action in electrical experiments has been perceived by all our senses, suppose that there can be less reality in it, than in earth, air, water, or fire, whose reality with respect to mankind depends on the evidence of those very senses. Electricity communicates ideas to every sense; it is light to the eye, odour to the nose, stroke to the touch, subacid to the taste.

If you apply heat, either by means of water, or any other method, to the heart of a viper or of an eel taken from the body of those animals, it will again begin to vibrate. Now heat is fire in action, and thus you see the same effect is produced as was effected in the palsied limb.

The reason why the hearts of vipers and eels, and such like animals, are put into motion by a power of the same nature, though in a less degree than that which moves the heart of larger animals, is, because they are extremely cold by nature, and therefore a less degree of fire actuates on their heart than on those of larger animals. It is not improbable, that the same degree of heat, which is necessary to keep a fowl alive, would destroy a frog or viper, and burst the cells of the tunica cellularis. After the heart of a viper has discontinued to beat with the application of any certain degree of heat, it will vibrate again on the application of a superior degree.

The heart, which in the open air had ceased to move with a certain degree of heat, will vibrate again in vacuo with the same degree; for the pressure of the atmosphere being removed, a less power is required to distend the fibres.

Dr. *Shebbeare* took the heart of an eel, which had been some time dead, and placing it on a card, put it on the conductor; the first motion that was communicated to it was its swelling, or the diastole of the ventricles, which not being immediately followed by the contraction or systole, he took the electrical spark therefrom, on which it contracted; it then dilated again, and upon the application of his finger again contracted; and thus having repeated it several times, the heart continued to perform its dyastole and systole, without being touched; and when it was removed it ceased, but began again upon being placed on the bar.

Lord *Bacon* has given us a very remarkable instance of the effect of fire upon the human heart. He says, "that upon the embowelling of a criminal, he had seen the heart of a man, after it was thrown into the fire, leap up for several times together, at first to the height of a foot and a half, and then gradually lower, to the best of his memory, for the space of seven or eight minutes.

Trace vital heat and motion from their source, and you will find these phenomena still more clearly illustrated. An egg, though it include all the parts necessary for the formation of an animal, will never produce a chicken, unless it is kept in a certain degree of heat for a certain time; which heat, regularly conducted, is all that is necessary to the production of an animal similar to the parent.

That there is nothing more necessary to the producing this animal from an egg, than common fire, has been long known and practised in Egypt, and demonstrated by Mr. *Reaumur*. There is no other vital principle transfused from the hen to the embryo, than from a common fire. Thus is fire plainly proved to be the first mover in the animal machine, and is the only active, material, or natural principle during its existence; and it is a principle absolutely necessary for the preservation of health, and generating wholesome fluids. Shall fire be allowed to have the power of beginning the vital motion in the womb, or egg, and shall it be refused the power of continuing it after the birth?

Now, for many reasons, which will be seen as we proceed, it appears that the fluid of fire passes by the nerves to the brain and spinal marrow, and from thence to the heart for the supplying the cause of involuntary motion, and that a sufficient quantity is always detained there to go to the muscles at particular times for the performing voluntary motion.

This fire (the reality of whose existence is proved by all the demonstrations which can attend the proof of any existence, and whose general properties are now well known) is lodged in the brain, medulla spinalis, ganglions, and nerves, and thence operates on all the different parts of the body. The diminution and waste of this fire is continually supplied from the earth.

The nerves, which are destined to the sense of feeling, are the conductors of this fire to the brain; while those which are destined to motion, are the conductors by which it is conveyed to the muscles. For a particular explanation of the manner in which it acts, I must refer you to Dr. *Shebbeare*'s masterly performance.

It is not the fluid of fire alone that constitutes and preserves the vital heat and vital motion; but it must for this purpose be brought into a certain state or degree of action, which, in a healthy man, amounts to 98° of *Fahrenheit*'s thermometer; and according to the degrees of heat originally destined to each animal, and the excess or decrease of it, will be the state of its activity and health.

Nor is it confined to animals; something of the same kind seems to take place in vegetables. The heat which produces an apple to perfection would never bring forth a pine-apple; and the firs, which thrive and look green on the bleak and snowy hills of Norway, would perish in the burning sands of Barca; whilst the spicy vegetables of the east, which breathe incessant sweets amid the glowing soil of Arabia, would languish and expire in that cold clime which breeds the lofty oak.

The heat which hatches the chicken from an egg would destroy the whole race of fishes, if it affected their spawn; and thus the very same element, which makes an animal complete in one degree, and in one species, destroys its existence in another species with the same degree.

The degree of heat, which would injure the life of a frog, would not be sufficient to keep the heart of a sheep in action. Health depends on a degree of heat which is natural to each animal, and which was first imparted to it by that Divine Intelligence, who is alone able to actuate and inform, and who has furnished us with powers to keep up this degree, and counteract, and throw off a greater.

In this account of vital heat and motion, there is nothing new supposed; no new property assigned either to fire or electricity; no new formation given to any part of the human body.

We require no more of the nerve than that it exists, and that it be a conductor of the electric fluid; which experiment proves, vital heat and vital motion are here as they are in nature, beginning together, and continuing so through life. Solar fire and the electric fluid are one and the same vivifying principle, actuating all the different orders of material beings: they are so radically the same, that in various instances you find that what was one becomes the other; and thus facts and philosophy are united; and the cause of natural life and motion is discovered by reason and experience to be the same with what our senses inform us to be intuitively the true one. And permit me to tell you, that in general, whenever the account given to explain the cause of any phenomena in nature, is contradictory to the obvious apprehension of the senses of a plain understanding, there is reason to suspect its truth. That to the agency of fire all animal motion and animal heat are owing is obvious to the meanest capacity; and if this element cease to act, or if it be disunited from the body, death is the certain consequence. Every part of nature affords facts to support this opinion. Contemplate the great luminary which enlightens the universe, and you will find every ray is fraught with fire, which it is ready to manifest on meeting a proper recipient. Without the genial warmth they communicate, both animal and vegetable life must cease, and all nature become one lifeless, torpid, dismal ruin.

All nature bears testimony to the existence of this etherial fluid, and to its incessant active energy. To us, indeed, it often remains latent; and peculiar circumstances are necessary to excite those signs which render its effects most visible to our senses. The ancients, viewing nature as she is, often attained more accurate notions of her operations than modern philosophers. These, by multiplying experiments, without first attaining a correct idea of the facts continually presented for observation in the great laboratory of nature, have often wasted their time and talents; and, in the end, have bewildered themselves in an inexplicable labyrinth, or at best, have only placed one species of ignorance in the deserted room of another.

The Platonists and Pythagoreans maintained, that fire was the great instrumental cause in the universe, subordinate to the Infinite Creative Mind; and that it actuated the macrocosm and animated the microcosm.

The old naturalists have universally maintained, that fire was in all bodies; and, however indistinctly they were able to write of it, what they wrote was true. *Theophrastus* has spoken of fire in terms that bespeak a considerable knowledge thereof. Far from supposing motion to be the cause, much further from supposing it to be the essence of fire, he asserts, that fire is a very distinct thing from the matter in which we see it lodged, and from the motions which we see excite it; and that it is, in its pure natural state, fine, etherial, imperceptible, and at perfect rest. He hints, that this fire was the breath which the Creator diffused in all matter, which, passing over the waters, made out of them metals, stones and earth; and asserts, that it is the instrument which he employs to give all things life and motion.

They in general considered earth and water, air and fire, as the component elements of all visible and known corporeal beings, and that life was conveyed to them through the elements of air and fire; that this fire was continually operating to apply and adjoin to these bodies the newly arrived matter, converting this matter into a substance of the same nature or form with that part to which it was applied, and thus fitting it for the growth or increase, as well as the aliment of the part. But then they also considered natural life as only possessed of these powers, because it was the immediate agent of mind: for mind is evidently the cause of form to all things formed by man; and the cause of union or conjunction to all things united or conjoined by art.

It is hardly possible not to agree in many respects with these ancient sages: for, when you look round with a philosophic eye, and contemplate the universe with sedulous attention, you will find that there is no effect either beautiful, great, marvellous, or terrible, but what proceeds from fire.

It can, therefore, be no matter of surprize, that after the discovery of electricity, it was considered as the physical cause of motion, irritability, &c. but it is surely a subject of regret, that medical men have shewn such reluctance to the investigation of this subject, and that too many have in every possible way endeavoured to discountenance its application in medicine; though the agency of this fluid, and its existence in animated nature, has been so fully proved by a variety of experiments, that there can be very little doubt that it is essentially connected with, and continually exerting its influence on the human frame. I shall here lay before you some further instances to corroborate what has been already advanced. By means of a small condensing plate, Mr. *Cavallo* obtained very sensible signs of electricity from various parts of his own body, and the head of almost any other person. The strong electricity obtained in frosty weather from silk stockings, &c. on being pulled off, as well as that obtained by combing the hair, have been long known. Among others, Mr. *Brydone* mentions a lady, who, on combing her hair in frosty weather in the dark, had observed sparks of fire to issue therefrom. This made him think of trying to collect the electrical fire from human hair alone. To this end, he desired a young lady to stand on wax, and comb her sister's hair, who was sitting in a chair before her; soon after she had begun to comb, the young lady on the wax was surprized to find her whole body electrified, and darting out sparks of fire against every object that approached her. Her hair was strongly electrical, and affected an electrometer at a considerable distance. He charged a metallic conductor from it, and in the space of a few minutes collected a sufficient quantity of fire to kindle common spirits; and, by means of a small jar, gave many smart strokes to all the company.

When the discoveries in this science, says Mr. *Brydone*, are further advanced, we may find, that what we call sensibility of nerves, and many other diseases, which are known only by name, are owing to the bodies being possessed of too large or too small a quantity of this subtile fluid, which is, perhaps, the vehicle of all our feelings. It is known, that in damp and hazy weather, when this fire is blunted and absorbed by the humidity, its activity is lessened, and what is collected is soon dissipated; then our spirits are more languid, and our sensibility is less acute. And, in the fierce wind at Naples, when the air seems totally deprived of it, the whole system is unstrung, and the nerves seem to lose both their tension and elasticity, till the north-west wind awakens the activity of the animating power, which soon restores the tone, and enlivens all nature, which seemed to droop and languish in its absence. Nor can this appear surprizing, if it is from the different state of this fire in the human body that the strictum and laxum proceeds, and not from any alteration in the fibres themselves, or their being more or less braced up (among which bracers cold has been reckoned one,) though the muscular parts of an animal are more braced when they are hot, and relaxed when they are cold.

From the perpetual electricity of the atmosphere, which is no longer a problem, as its existence and agency in that mass of air which surrounds our globe, has been ascertained by numerous, clear, and decisive experiments, it seems but just to infer, that it must exert a certain influence on all the beings contained therein, and principally on organized bodies, among which the human frame claims the pre-eminence.

But there is no necessity for deductions from a general view of nature, for we are now in possession of facts, which prove that it is a principal agent in promoting the functions of animated beings; as in the gymnotus electricus torpedo, and silurus electricus. For the similitude established between the electrical fluid of these animals, and that of nature at large, is such that in a physical sense may be considered the same.

OF THE LATER EXPERIMENTS ON ANIMAL ELECTRICITY.

When Mr. *Walsh* first attributed the sensations produced by the torpedo, &c. to electricity, his opinions, and the inferences deduced from his experiments, were vehemently opposed by most of the best electricians of the day: the conceptions of these men being limited to the minutiæ of experiments, they were incapable of grasping a more extensive subject, or one that was not in all respects conformable to the appearances they were used to. Whereas a just view of things should have prepared them to expect various anomalies, while they were investigating the nature of an invisible and subtile agent, subject to a variety of modifications from the substance through which it passes, or with which it may be combined. Hence, in the pursuit of animal electricity, you must not expect to meet with every electric sign; as, from the very nature of its connexion with animated beings, it will certainly acquire properties that are not to be found when it is disengaged therefrom.

Before I relate any of the experiments of *Valli*, &c. I shall lay before you those principles, which I conceive will throw great light on the subject of animal electricity, and by which they may be reconciled to the general agency of nature. You have seen, by a great variety of experiments, that electricity is first rendered sensible by a solution of continuity; you have also every reason to suppose, that the electric matter is carrying on its most important functions when we are unable to perceive any signs of electricity; you have seen that the electric matter, and what we term electricity, are not inseparable beings, that the one may subsist when the other ceases to appear. As the air may occupy a space without producing sound, so the electric matter may reside in a body without exhibiting any electric signs. We know also by universal observation, as well as partial experiments, that there is a principle in all bodies which is continually endeavouring to extend their form, but whose energies are continually counteracted by an exterior force. Now it must be evident, that every solution of continuity will give an opportunity for this expansive dilating substance to escape, when it puts on new and unexpected appearances. Now, as we know this expanding substance is fire, and have a proof that on its escape it exhibits electric signs, we have a further confirmation of the identity of these elements.

I think this view of the subject is in itself a sufficient refutation of Dr. *Munro*'s attempt to prove that the nervous fluid or energy is not the same with the electrical;* though many other arguments may be adduced to answer the same purpose.

His difficulty in conceiving how the electrical fluid can be accumulated within our nervous system, is not greater than that of conceiving how it is accumulated amidst a conducting fluid in the torpedo, &c. nor indeed than of its being accumulated in the Leyden phial, as glass is now known to be permeable thereto. But the difficulty with respect to animals vanishes, when we consider that electrical appearances are occasioned by a state of the fluid altogether different from that under which it exists in the animal frame; when it is in the latter, its powers are united, and its operations imperceptible; when it appears as electricity, its powers are divided and some of their effects rendered sensible.

So far as mechanical stimuli have any relation to fire, so far they will be in some degree similar to the electrical fluid and act in the same manner; for, stimulants act only as they are the vehicles of fire. The second objection, therefore, of the professor falls to the ground. The same reasoning applies to his sixth objection.

His fourth reason, so far from proving that the nervous and electrical fluids are not the same, may be considered as a clear proof of their identity, for the two electrical powers always act in opposite directions.

On the same principle, the nervous energy (the electrical fluid in its united state) cannot pass readily up or down a nerve that has been tied or cut, for the tying or cutting the nerve changes the state of the fluid.

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* *Munro*'s Experiments on the Nervous System.

Before I proceed to give you an account of the experiments relating to animal electricity, I shall lay before you some remarks of the Rev. Mr. *William Jones*,* from whom we have already profited so much in the course of these Lectures, and which are intimately connected with our subject. "As the force of the electrical fluid, says he, is principally exerted on the nerves and tendons of the body, there is reason to believe that this fluid is the same with that something, which many physicians have discoursed upon under the name of animal spirits. The nerves do not appear as if they were designed to admit any animal fluid or liquor, unless it be an indolent lymph necessary to keep them moist: but their pellucidity indicates that they are properly adapted to give a direct passage to the fluid light; for they are transparent, and that not transversely, but longitudinally, or in the direction of their fibres. This Mr. *Jones* observed accidentally, as some eyes of sheep and oxen which he had procured for dissection lay on the table; one of these eyes shone in the day time much in the same manner as the eyes of some animals do in the dark; on examining into this circumstance, he found, that if his hand were interposed between the nearest window and the extremity of the optic nerve, a part of which nearly an inch in length remained with the eye, and was accidentally pointed towards the window, the light immediately disappeared."

From this he was led to consider, whether the light that appears in the eyes of some animals in the night time, is really a reflexion of light from the eye, as is commonly supposed; or whether it does not rather pass into the eye, through the optic nerve, from the body of the animal? It is not easy to conceive how this shining can be occasioned by a reflexion of light from the choroides in the bottom of the eye, when the light to be reflected (as in a dark night) is not visible before its entrance into the eye. If a candle be held before the eyes of a dog, and you place yourself in the line of reflexion, the light will be visibly reflected from his eyes, because the illumination is sufficiently strong; but when there is no visible illumination at all, how should it account for the like effect? Whence it is more reasonable, that this appearance should be owing to a light from within the body of the animal, which being weaker than the light of the day, but stronger than the light of the night, is visible in the night but not in the day. The light of other bodies which shine in the dark is inherent in those bodies, as in putrifying veal, fish, rotten wood, phosphorus, the glow-worm, &c. concerning the last of these, the eminent anatomist and philosopher, *T. Bartholine*, has the following observation. If a glow-worm be examined, it will appear to have a lucid liquor in the hinder part of its body, where the heart is placed, by which the heart is moved and illuminated; and this fluid retains its light so long as the heart of the insect retains its life and motion.

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* *Jones*'s Essay on the First Principles of Natural Philosophy, page 206.

Dr. *Priestley*, in his *Heads of Lectures on a Course of Experimental Philosophy*, has given so excellent and compendious a view of the principal experiments that have been made by *Valli* and others, to determine the electricity of animals, that I cannot do better than lay it before you; which I the more readily do, as it will save us from the disgusting detail of a variety of cruel experiments; experiments that I hope you will never be induced to repeat.

One alone will suffice to give you an idea of the nature of these operations.

Mr. *Valli* opened the abdomen of a frog, in order to lay bare the spine of the back, and discover the crural nerves which issue from it; a few lines above this point he cut the animal in two, and passing his scissars immediately under the origin of these nerves, removed the remaining portion of the vertebral column, so as only to leave the vertebral which united the bundle of nerves; this portion of the vertebræ was enveloped with a piece of sheet lead; the coated part was touched with one end of a metallic conductor, and with the other, the surface of the thighs which were previously stripped of their skins. The movements produced thereby were violent and continued for a long time.

Having thus explained to you the manner in which the animal is prepared for these experiments, I shall proceed to point out the principal results, as furnished by Dr. *Priestley*.

The nerve of the limb of an animal being laid bare, and surrounded with a piece of sheet-lead, or tin-foil, if a communication be formed between the nerve thus armed, and any of the neighbouring muscles by means of a piece of zinc, strong contractions will be produced in the limb.

If a portion of the nerve which has been laid bare be armed as above, contractions will be produced as powerfully, by forming the communication between the armed and bare part of the nerve, as between the armed part and muscle.

A similar effect is produced by arming a nerve, and simply touching the armed part of the nerve with the metallic conductor.

Contractions will take place if a muscle be armed, and a communication be formed by means of the conductor between it and a neighbouring nerve;

the same effect will be produced, if the communication be formed between the armed muscle and another muscle which is contiguous to it.

Contractions may be produced in the limb of an animal, by bringing the pieces of metal into contact with each other at some distance from the limb, provided the latter make part of a line of communication between the two metallic conductors.

The experiment which proves this is made in the following manner. The amputated limb of an animal being placed upon a table, let the operator hold with one hand the principal nerve, previously laid bare, and in the other let him hold a piece of zinc; let a small plate of lead or silver be then laid upon the table at some distance from the limb, and a communication be formed by means of water between the limb and the part of the table where the metal is lying. If the operator touch the piece of silver with the zinc, contractions will be produced in the limb the moment that the metals come into contact with each other. The same effect will be produced, if the two pieces of metal be previously placed in contact, and the operator touch one of them with his finger. This fact was discovered by Mr. *William Cruikshank.*

Contractions can be produced in the amputated leg of a frog, by putting it into water, and bringing the two metals into contact with each other, at a small distance from the limb.

The influence which has passed through, and excited contractions in one limb, may be made to pass through, and excite contractions in another limb. In performing this experiment, it is necessary to attend to the following circumstances; let two amputated limbs of a frog be taken, let one of them be laid upon a table, and its foot be folded in a piece of silver; let a person lift up the nerve of this limb with a silver probe, and another person hold in his hand a piece of zinc, with which he is to touch the silver including the foot; let the person holding the zinc in one hand, catch with the other the nerve of the second limb, and he who touches the nerve of the first limb is to hold in his other hand the foot of the second; let the zinc now be applied to the silver including the foot of the first limb, and contractions will immediately be excited in both limbs.

The heart is the only involuntary muscle, in which contractions can be excited by these experiments; contractions are produced more strongly, the farther the coating is placed from the origin of the nerve.

Animals which were almost dead, have been found to be considerably revived by exciting this influence. When these experiments are repeated upon an animal that has been killed by opium, or by the electric shock, very slight contractions are produced; and no contractions whatever will take place in an animal that has been killed by corrosive sublimate, or that has been starved to death. Zinc appears to be the best exciter when applied to gold, silver, molybdena, steel, or copper; the latter metals, however, excite but feeble contractions when applied to each other; next to zinc, in contact with these metals, tin and lead appear to be the most powerful exciters.

It has been found, that if a plate of zinc is applied to the upper part of the point of the tongue, and a plate of silver to its under part, on bringing the two metals into contact with each other, a pungent disagreeable feeling, which it is difficult to describe, is produced in the point of the tongue. And if a plate of zinc is placed between the upper lip and the gums, and a plate of gold applied to the upper or under part of the tongue, on bringing these two metals into contact with each other, the person imagines that he sees a flash of lightning, which however a by-stander in a darkened room does not perceive; and the person performing the experiment perceives the flash though he is hood-winked.*

After performing this experiment repeatedly, Dr. *Munro* constantly felt a pain in his upper jaw, at the place to which the zinc had been applied, which continued for an hour or more; and in one experiment, after he had applied a blunt probe of zinc to the septum narium, and repeatedly touched with a crown piece of silver applied to the tongue, and thereby produced the appearance of a flash, several drops of blood fell from that nostril; and Dr. *Fowler*, after making such an experiment on his ears, observed a similar effect.

RESEMBLANCE OF THE FLUID PUT IN MOTION BY THE FOREGOING EXPERIMENT, TO THE ELECTRICAL FLUID.†

The fluid set in motion by the application of the metals to each other, and to animal bodies, or to water, agrees with or resembles the electrical fluid in the following respects:

Like the electrical fluid, it communicates the sense of pungency to the tongue.

Like the electrical fluid, it is conveyed readily by water, blood, the bodies of animals, the metals; and is arrested in its course by glass, sealing-wax, &c.

It passes with similar rapidity through the bodies of animals.

Like the electrical fluid, it excites the activity of the vessels of a living animal; as the pain it gives and hemorrhagy it produces seem to prove. Hence, perhaps, it might be employed with advantage in amenorrhœa. It excites convulsions of the muscles, in the same manner, and with the same effects as electricity.

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* *Munro's* Experiments on the Nervous System, p. 25.

† Ibid p. 38.

When the metals and animal are kept steadily in contact with each other, the convulsions cease, or an equilibrium seems to be produced, as after discharging the Leyden phial.

GENERAL OBSERVATIONS.

A view of the great agents in nature naturally leads us to consider the opinions of those who wish to set religion and reason in opposition to each other, and to suppose that philosophy and revelation can never agree. But, in opposition to such insidious attempts, attempts which never were designed to enlarge the mind or to improve the heart, it may easily be made to appear that, take philosophy in its most improved state, enriched by the discoveries of ages, examined by the test of the closest reasoning, elevated above the fallacies of the senses and of appearances; and yet, in this improved state, it shall be found perfectly to correspond with the philosophy of scripture, rightly understood. The word of God is as perfect as his work. Both proceed from the one fountain of truth, who cannot contradict himself. HIS word and HIS work mutually illustrate each other: the one is not to be understood without the other; for both are the offsprings of divine love, manifested in wisdom, and exercised in power.

Creation may be considered as the grand chain of causes and effects, intimately connected together. It is the work of Omnipotence, guided by infinite wisdom, and excited to work by communicative goodness. But, do we not obtain wrong ideas on this important subject, if we imagine that any part of this grand system stands unconnected? or, as if the Great Master Builder was obliged to collect discordant materials from different parts, and overcoming the repugnance of their natures, to form one whole out of these heterogeneous substances? Whereas, the truth appears to be, that in his divine hand, the one naturally and orderly produces the other; that, which was the effect of a prior principle, becomes the cause of that which follows it immediately; and again, this effect becomes an instrumental cause in its turn; and is thus extended in a long series, until all are completed in outward nature.

Let us examine how this will agree with the Mosaical account of the creation; for, although we may readily allow, that that book contains more interesting and important subjects than the detail of the mere creation and formation of this material system; yet the natural account, when rightly understood, may be found to be most accurate, philosophical, and just. The great and spiritual truths, conveyed under that form, may yet be delivered down to us in a vehicle of the most accurate philosophical truth; the stricter the truth, the greater and more perfect the analogy and correspondence; but it seems to have been the peculiar fate of these sublime and ancient writings of the Hebrew Sage, that they have been supposed to contain what they did not, whilst their real and most important contents have been greatly overlooked. The ideas of the Divine Mind disclosed, the energies of his almighty will exerted, produced motion in different degrees, as the instrumental cause for future productions. Hence the motion of spirits, of minds, of life, of thought, of light, of the heavenly bodies, of blood, and of the sap. Hence this motion, dependent and continued from one source of life and motion, may be considered as the key of natural knowledge, which opens the temple of physical truth. Motion is the visible discovery of the divine hand; motion is the grand connecting link between the spiritual and natural worlds; by this the energies of the one are impressed on the other.

This motion, proceeding from a pure and superior system, was at first most perfect and full, unencumbered by matter, unimpeded by obstructions.

Now, in the first day (or in the first state of creating things, for as yet there was no sun and earth, and therefore no measure of day and night), in this first state of things, the Scripture says, light was formed, or rather the matter of light, by the means of pure original motion. Now the matter of light is elementary fire. This is evident from the most intimate relation between fire and light; light being only an effect, an outward visible manifestation of latent fire.

This pure elementary fire, the matter or substance of light, produces that rapid motion of light from the sun or stars to the earth, travelling with such amazing velocity. Fire and light combined, produced air, or the first and purest etherial particles; and therefore, in the Mosaical account, the firmament, the expanse, or the atmosphere of the air, was the second day's work, or the second state of things in their progress to perfection and fulness. This elementary principle is not so subtile and active as its parents, fire and light; yet it is more subtile and active than vapour or water; therefore it holds the intermediate rank between these, and is a connecting link in the great chain, as it is produced by fire and light; so again, when partly deprived of these, it is the instrumental cause to form the vapours and water.

That fire and light produce air may be illustrated by various experiments; the respiration of plants, and the purity of the air, which they produce, when exposed to the agency of light; and the great quantities of different airs produced in various chemical experiments by the activity of fire.

Air condensed, exposed to obstructions, and thus deprived of the greatest portion of its etherial fire, becomes first vapour; and as the fire dissipates, and the motion ceases, it becomes water in the various forms of mist, dew, rain, &c. In this state, it is almost entirely deprived of its original motion; is less subtile, and more gross; is become an object of the outward senses, and is subject to the laws of gravitation.

Water is the great support of animal and vegetable substances, which at length are reduced to earth in their various changes, from the first principles of active nature, down to the lowest, grossest material form; from the fountain of life, from the architypal ideas of the Divine Mind, through spirits to fire, light, ether, air, water, earth, down to sluggish inert matter.

Fire, light, air, and water, may then be considered as the grand agents in nature. The earth is, as it were, a basis for them to rest and to work upon. In these, the circulation of motion in its descent and degrees is preserved, and the earth is a nidus where they rest, and where their effects are manifested. Thus there was a regular and beautiful descent from the spiritual to the natural world, from motion to rest. The wondrous fabric of the earth was not built of discordant materials, of jarring elements, forcibly restrained by the divine hand continually checking them; but the homogeneous substance arose in a wise and orderly series. Each part being preparatory for that which was to succeed; every thing being a link in the great chain of order and usefulness; an instrumental cause to produce the succeeding effect, until all was finished and complete, nature stood perfect in outward matter: creation was no longer all fire, light, air, or water, but each retained its respective rank; and the gross material world was produced, able to sustain minerals, plants, animals, and man.

Thus did the Divine Architect accomplish this great and stupendous work by the most simple means; by a regular descent from the spiritual to the natural world; a continued series proceeding from the highest to the lowest, from the purest motion to inactivity, from the highest principles of intelligent mind down to the lowest, grossest, heaviest matter. Thus were all things ordered in infinite wisdom: causes were employed most simple and prolific, to accomplish the end designed. Creation was accomplished; the earth stood complete; the work of divine power resulting from divine wisdom and mercy. It was made the theatre of his goodness, on which he might display it, and communicate it to his various creatures, who thus might rejoice in their existence; and manifest his praise, by enjoying happiness, and rising in perfection through endless ages.

Thus was the earth designed to be the repository of the human race, the seminary of men; until, full of years and wisdom, they were ripe for a happier change; were prepared to quit the perishing body, and to be transplanted into a paradise of endless delights.

The whole material system was also a volume of divine instruction opened to man, in which he might read and understand and live for ever; in which he might discover immense benevolence, design, and order, and thus be led to understand and adore him, who is the source of all things.

LECTURE L.

ON MAGNETISM.*

Though the phenomena of the magnet have for many ages engaged the attention of natural philosophers, both from their singularity and importance; we are not yet in possession of any hypothesis that will satisfactorily account for the various properties of the magnet, or point out those links of the chain that connect it with the other phenomena of the universe.

It is known by the works of *Plato* and *Aristotle*, that the ancients were acquainted with the attractive and repulsive powers of the magnet; but it does not appear, that they knew of its pointing to the pole, or the use of the compass. That property of the magnet, whereby, when properly suspended, it turns towards the north pole, renders it of the utmost service to mankind in general, but more particularly to an Englishman; the riches and power of whose country depend on navigation.

The powers of the magnet excited the wonders of the ancients; they were to them inexplicable, and remain so. Posterity, instead of being able to remove the difficulties, have only by their researches found out new wonders equally inexplicable. All, therefore, that I shall be able to do, will be to relate to you the principal qualities of this curious phenomenon. "The magnet is a proof, that nature has many secrets, and that philosophy, if contented with present knowledge, foregoes most valuable and interesting discoveries, towards which, perhaps, the previous steps are already trodden." From its action on the compass in all parts of the world it is plain, that its influence is universal. From our knowledge of this we are naturally led to suppose, that there may be other invisible agents exerting their influence on us, and on our globe.

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* See my Essay on Magnetism.

Let the modern philosopher,* who denies the existence of a God, because he cannot perceive him with his corporeal eyes, tell you what magnetism is, and how it exists. Let him, who will understand every thing that exists, before he allows of its existence, first employ himself here; and when he has given the world a proof of his powers, let him attempt an higher subject.

The loadstone, leading-stone, or natural magnet, is an iron ore or ferruginous stone, found in the bowels of the earth, generally in iron mines, of all forms and sizes, and of various colours. It is endowed with the property of attracting iron; and of both pointing itself, and also enabling a needle, touched upon it, and duly poised, to point towards the poles of the world.

Loadstones are in general very hard and brittle, and for the most part more vigorous in proportion to their degree of hardness. Considerable portions of iron may be extracted from them. *Newman* says, that they are almost totally soluble in spirit of nitre, and partially in the vitriolic and marine acids.

Mr. *Kirwan* says, that the magnet seems to contain a small quantity of sulphur, it is often contaminated with a mixture of quartz and argill; it is possible it may contain nickel, for this, when purified to a certain degree, acquires the properties of a magnet; but its constitution has not as yet been properly examined.*

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* *Condorcet*, and many of his school, have laughed at mankind for believing in an invisible Being.

Artificial magnets, which are made of steel, are now generally used in preference to the natural magnet; not only as they may be procured with greater ease, but because they are far superior to the natural magnet in strength, and communicate the magnetic virtue more powerfully, and may be varied in their form more easily, so that the natural magnet is now very little esteemed, except as a curiosity.

The power of attracting iron, &c. possessed by the loadstone, which is communicable to iron and steel, is called *magnetism.* It has been supposed, that iron and the loadstone were the only two bodies which could be rendered magnetical; but it now appears, that nickel, when purified from iron, becomes more instead of less magnetic, and acquires, what iron does not, the properties of a magnet.†

A rod or bar of iron or steel, to which a permanent polarity has been communicated, is called a *magnet.*

The points in a magnet which seem to possess the greatest power, or in which the virtue seems to be concentrated, are termed *the poles of a magnet.*

The magnetical meridian is a vertical circle in the heavens, which intersects the horizon in the points to which the magnetical needle, when at rest, is directed.

The axis of a magnet is a right line, which passes from one pole to the other.

The equator of a magnet is a line perpendicular to the axis of the magnet, and exactly between the two poles.

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* *Kirwan*'s Elements of Mineralogy. In the second edition, 1796, p. 158, of this excellent work, are given further and more correct particulars of this curious mineral. EDIT.

† Ibid, p. 281.

The distinguishing and characteristic properties of a magnet, are.

1. Its attractive and repulsive powers.
2. The force by which it places itself, when suspended freely, in a certain direction towards the poles of the earth.
3. Its dip or inclination towards a point below the horizon.
4. The property which its possesses of communicating the foregoing powers to iron or steel.

OF THE TENDENCY OF IRON AND A MAGNET TO APPROACH EACH OTHER.

This curious property of the magnet was that by which it was first discovered, and by which it engaged the attention of the curious.

Every substance that contains iron is more or less attracted by the magnet. And so universally is this metal disseminated, that there are very few substances that are not in some degree capable of being attracted by the magnet. You will find it in animals, vegetables, minerals, and even in the air.*

Iron is attracted with different degrees of force, according to the different states of its existence; but it never becomes quite insensible to the magnetic power. Even the purest calx, or the completest solution ever made of the metal, when accurately examined, is found to be in some degree obedient to the magnet.

TO ASCERTAIN WHETHER A BODY HAS ANY IRON, OR IS CAPABLE OF BEING ATTRACTED BY THE MAGNET.

If the given body contains evidently a large quantity of iron, on bringing a magnet in contact therewith, you will find them adhere so strongly as to require a certain degree of force to separate them. If the body be not sensibly attracted by the magnet in this way, then you may float it by a piece of wood or cork on water; in this situation it is more easily acted on, and consequently small quantities of iron are readily discovered. The magnet should be presented sideways to the body, and when it is at rest, it is sometimes necessary to bring the magnet within one tenth of an inch distance from the swimming body in order to perceive the attraction.

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* *Cavallo* on Magnetism, p. 66.

A still smaller degree of attraction may be discovered by placing the given body upon quicksilver, and then presenting a magnet to it. The vessel, in which the quicksilver is contained, should be at least six inches in diameter, otherwise the curvature of the fluid will be perpetually carrying the body towards the sides of the vessel. The quicksilver should be pure, and occasionally cleared by passing it through a funnel of clean writing paper; the smaller the aperture of the funnel, the better it will answer the purpose. The air should be agitated as little as possible. Attending to these precautions, you will seldom fail to discover whether a body contains any ferruginous particles.*

I place a piece of iron on a cork, and put the cork into a bason of water. I present a magnet to it, and it is attracted thereby, and follows the magnet, so that I can move it without touching wherever I please. On this principle, many ingenious and entertaining pieces of mechanism have been contrived.

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* A fine magnetic needle about four or five inches long, suspended on a pointed stand, as shewn at *plate* 2, *fig.* 16, I think the most sensible and convenient apparatus for this purpose.

EDIT.

The tendency between the magnet and the iron is reciprocal; for, if the magnet be put on the cork, it will follow the iron in the same manner as this followed the magnet. And this attraction takes place, although a piece of paper, glass, brass, &c. be interposed between the magnet and the iron.

The reciprocal tendency of iron to a magnet, and of a magnet to iron, is pleasingly illustrated by suspending a magnet under the scale of a ballance, and counterpoising it by weights in the other scale; when thus counterpoised, bring a piece of iron towards it, and the magnet will immediately descend. Reverse the experiment by suspending the iron from the scale, and the iron will now descend and follow the magnet.

I place a magnet upon a stand, to raise it some distance from the table; I shall bring a small sewing needle towards it, keeping the thread which is in the needle in my hand, to prevent the needle from fixing itself to the magnet; and the needle endeavouring on one hand to fly to the magnet, and being withheld on the other by the thread, remains pleasingly suspended in the air.

Mathematicians have endeavoured to compute the force with which the magnetic attraction acts at different distances, but hitherto without success. No law has been ascertained, upon which any dependance can be placed.

Though many experiments have been made to discover, whether the force by which two magnets are repelled or attracted, acts only to a certain distance; whether the degrees of its action within, and at this distance, is uniform or variable, and in what proportion, to the distances it increases or diminishes; yet we can only infer from them, that the magnetic power extends further at some times than it does at others, and that the sphere of its action is variable.

The smaller the loadstone or the magnet is, the greater is its force, *cæteris paribus*, in proportion to its size. When the axis of a magnet is short, and of course its poles very near, their action on each other weakens the magnetic force. A variety of other causes will also occasion great irregularity in the attraction of magnetism. The attraction is, as I shall shew you, always strongest at the poles of the magnet; and most so when the body is near the magnet, but diminishes as either recedes from the other. It appears also from experiment, that a magnet attracts another magnet with less force than it does a piece of iron.

OF THE POLES OF A MAGNET.

It has been already observed to you, that there are certain points of a magnet called the *poles*, which are possessed of the greatest magnetic force, and in which its virtues seem as it were to be concentrated. This I shall prove by an easy experiment: here are several small iron balls; I shall try what number of these the magnetic bar will sustain at different places, and you find that it supports the greatest number near the ends; this will answer our purpose in the first instance; you will find this further confirmed by the subsequent experiments, designed to point out with accuracy the situation of the poles of a magnet.

I have covered a pane of glass with writing paper, that the difference in colour may enable us to discern more distinctly what effect a magnet has on steel filings strewed over the paper; I place this pane over a magnet, and sift some fine steel filings thereon; these you see arrange themselves in a very curious manner; those points from which the curves seem to rise, and over which the filings stand in an erect position, are the poles of the magnet.

Here is a small needle inclosed in a glass ball; move this over a magnetic bar, and the needle will be perpendicular to the bar, when it is over either of the poles.

The poles of a magnet may be ascertained with great accuracy by means of a small dipping needle, *plate* 2, *fig.* 7, *(Electricity)*: place this on a magnet, and move it backwards and forwards till the needle is perpendicular to the magnet, it will then point directly to one of the poles. When it is between the north and south poles, so that their mutual actions ballance each other, the center of the needle will stand over what is called the equator of the magnet, and the needle will be exactly parallel to the bar; between this situation and the poles, it inclines to the bar in different angles, according to its distance from the poles.

OF THE ACTION OF THE MAGNETIC POLES ON EACH OTHER.

In the action of the magnetic virtue at the poles, there is a strong similarity with that of electricity; thus the contrary, or north and south poles of two magnets attract each other, but poles of the same name, as two north or two south poles, repel each other.

Suspend on a point a touched needle, then present towards its north pole the south pole of a magnet, and it will be attracted by, and fly towards it; present the other pole of the magnet, and the needle will fly from it.

Strew a few steel filings upon a pane of glass, put either the north or south pole of one of the bars under the pane; the filings will rise upon the glass as the magnet approaches. Bring the same pole of the other bar directly over that under the glass, and when it is at a proper distance, the steel filings will drop flat on the pane.

Fix two needles horizontally in two pieces of cork, and put them in water; if the poles of the same name are placed together, they will mutually repel each other. If the poles of a contrary denomination are turned towards each other, they will be attracted and join.

Dip the north or south ends of two magnets in steel filings, which will hang in clusters from the end of the bars; bring the ends of the bars towards each other, and the steel filings on one bar will recede from those on the other. Dip the south pole of one magnet, and the north pole of the other, into steel filings, and bring the ends near to each other, and the tufts of filings will unite, forming small circular arches.

THE ACTION OF THE MAGNETIC POLES RENDERED VISIBLE BY STEEL FILINGS.

I place the glass pane covered with paper over a magnetical bar, and strew it over with steel filings; on striking the glass gently, the filings dispose themselves in such a manner, as to represent with exactness the course of the magnetic matter. The curves, by which it seems to go from pole to pole, are pleasingly indicated by the arrangement of the filings; the larger curves rise from one polar surface and extend to the other; they are larger in proportion as they rise nearer the axis or center of the polar surface; the interior curves are smaller and smaller in proportion to their distance from the end, see *plate* 2, *fig*. 8. The greater the distance between the poles of a magnet, the larger are the curves which arise from the polar surface.

Let two magnets be placed in a straight line at a small distance from each other, the south pole of the one opposed to the north of the other; lay a pane of glass over them, sprinkle it with steel filings, and then strike the pane gently with a key, and the filings will arrange themselves in the direction of the magnetic virtue; those that lie between the two polar surfaces, and near the common axis, are disposed in straight lines, going from the north pole of one to the south pole of the other, as if uniting and joining together, *plate* 2, *fig.* 9.

Place two north or two south poles under a pane of glass, on which iron filings have been strewed, and the filings will be disposed into curves, which seem to turn back and avoid each other, *plate* 2, *fig.* 10.

In magnetism, as well as in electricity, it is not the mere matter that is attracted, but the state of the magnetic fluid therein, so that the body always becomes magnetic before it is attracted; and hence there is no magnetic attraction but between the contrary poles of two magnets.

When a piece of iron, or any other substance that contains iron, is brought within a certain distance of a magnet, the powers thereof are separated, and it becomes itself a magnet, having poles, attractive power, and every property of a real magnet. That part which is nearest the magnet has a contrary polarity.

The magnetism that soft iron acquires, when placed within the influence of a magnet only lasts while it continues in that situation, but disappears as soon as it is removed. But with hard iron, and particularly with steel, the case is quite different. For the harder the iron, or the steel, the more permanent is the magnetism it acquires; but it is also more difficult to render it magnetic.

Thus if two pieces, one of soft iron, the other of hard steel, but both of the same shape and size, be brought within the influence of a magnet, and at the same distance, you will find the iron appear more magnetical than the steel; but when the magnet is removed, the soft iron instantly loses its magnetism, whereas the steel will preserve it for a long time.

A magnet will therefore attract soft iron more forcibly than hard iron, because it can render it more strongly magnetical.

In the foregoing experiments, the steel filings became so many little magnets, with contrary poles. On the same principles, a large key, or any other untouched piece of iron, will attract and support a small piece of iron, while it is near the pole of a magnet, but will let it fall when removed therefrom.

A ball of soft iron, in contact with a magnet, will attract a second ball, and that a third, till the influence becomes too weak to support a greater weight.

Here is a small spinner, *plate* 2, *fig*. 11, with an iron axis; I spin the spinner, and then take it up by a magnet, and you will not only find that it will continue spinning longer than if it were left to whirl on the table, but a second and a third whirligig may be suspended one under another, and yet continue in motion. The number suspended depends on the strength of the magnet.

OF MAGNETIC CENTERS.

There is a point between the two poles, where the magnet has no attraction nor repulsion; this point is called the *magnetic center*, though it is not always exactly between the two poles.

Pass the dipping needle, *plate* 2, *fig*. 7, over a magnetic bar, and you will find a place between the two poles, where the needle will be parallel to the bar; but if you move it ever so little from thence, it immediately inclines towards the poles, and when over either pole, is perpendicular to the bar.

This effect is also pleasingly exhibited by surrounding a magnet with small compass needles. I place the needles on these brass stands, so that they may be nearly in the same place with the bar, and you see those near the ends incline towards the pole, but that the two needles near the middle of the bar are parallel thereto, not inclining to either pole, see *plate* 2, *fig.* 12. You may also observe, that the north pole of the magnet attracts the south poles of all the needles, and the south, the north of the needles.

Lay a number of magnetic bars in a straight line with the north and south poles together, pass the dipping needle over them, and you will find a magnetic center at each place of contact, the union of the two powers destroying their action; separate them, and you have the north and south poles as at first.

Upon the same principles, if a magnetic bar be broken into any two parts, each part becomes a magnet, having two poles; the ends of which next to where it was broken acquiring a polarity contrary to the other end. Place a magnetic needle upon one of the stands, and when the needle is steady, place an iron bar of about eight inches long and between a quarter of an inch and one inch in thickness, upon the stand, so that one end of it may be on one side of the north pole of the needle, and so near it as to draw it a little way out of its natural direction. In this situation, approach gradually the north pole of a magnet, to the other extremity of the bar, and you will see that the needle's north end will recede from the bar more and more, in proportion as the magnet is brought nearer to the bar. If the experiment be repeated, with only this difference, *viz.* that the south pole of the magnet be directed towards the iron bar, then the north end of the needle will advance nearer and nearer to the bar, in proportion as the south extremity of the magnet is brought nearer to the iron.

The reason of this phenomenon is, that, by the approach of the north pole of the magnet, in the first case, the extremity of the iron bar which lies next to it acquires a south polarity, and, of course, the opposite extremity acquires the north polarity; in consequence of which the needle is repelled, because magnetic poles of the same name repel each other; but in the second case, when the south pole of the magnet is brought near the bar, the end of the bar which is next to it acquires the north polarity, and the opposite end acquiring the south polarity, attracts the north end of the needle.

If, whilst the pole of the magnet stands contiguous to one end of the bar, a small magnetic needle be presented within a certain distance to various parts of the surface of the latter, it will be observed, by the attraction and repulsion of the needle, that that half of the bar which is next to the magnet possesses the contrary polarity, and the other half the same polarity with the pole of the magnet that is applied to the iron.

The magnetic center, however, or the limit between the polarities, is not always in the middle of the bar; it is generally nearer that end which is presented to the magnet. This difference is greater as the magnet is weaker, and the length of the bar increases; but when the bar exceeds a certain length, which depends on the strength of the magnet, then the bar acquires several successive poles, *viz.* when the north pole of the magnet is contiguous to one of its extremities, that extremity becomes a south pole; a few inches farther on you will have a north polarity, then a south polarity, and so on. In this case, the first magnetic center comes very near that end of the bar which stands next to the magnet, and other magnetic centers are formed between every pair of successive poles.

Those successive poles become weaker and weaker in power according as they recede from that end of the bar which is contiguous to the magnet; so that in a pretty extended bar, they quite vanish long before they come to the farther end of it; hence, if one pole of a magnet be applied to the end of a long bar, the other end of the bar will not thereby acquire any magnetism. This will happen, when a magnet, capable of lifting about two pounds weight of iron, is applied to one extremity of an iron bar about one inch square and about five feet long. On removing the magnet, the bar, if of soft iron, will immediately lose all its magnetism; otherwise it will retain it a longer or shorter time, in proportion to its hardness.

TO RENDER IRON AND STEEL MAGNETIC.

The communication of the magnetic power to iron and steel bars, is termed by artists *touching a needle*, *a bar*, &c. To give a detail of the various processes used by different artists for communicating magnetism to iron, would take up too much of our time; I shall, therefore, only mention two methods, which you will find adequate to every common purpose.

I first place two magnets,* A, B, *plate* 2, *fig.* 13, in a straight line, the north end of one opposed to the south end of the other, but at such a distance that the bar to be touched may rest upon them, taking care that the end I designed for the south be laid upon the north end of one bar, and the north end on the south pole of the other bar.

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* The longer and stronger these are, the better they will answer the purpose.

I now take two other bars, D and E, and apply the north end of D * and the south end of E to the middle of the untouched bar C, elevating their other ends so as to form an acute angle with the said bar. I now separate D and E, drawing them different ways along the surface of the bar C, but preserving the same elevation all the way; I remove D and E to the distance of a foot or more from the untouched bar C, and bringing the north and south ends in contact, I apply them again to the middle of the bar C, and shall repeat the process three or four times; after which I shall touch the other three surfaces in the same manner, and the bar will thereby have acquired a strong and permanent magnetism. This was one of the methods used by Dr. *Knight*, who first taught us the great advantage that might be obtained from the use of magnetic bars, giving by their means a magnetism to compass needles double in force to that which the strongest natural loadstone could communicate. He was the first also who found the way of working on the natural magnet, so as to increase its power in a great degree, and of inverting its poles at pleasure.

You may readily communicate the virtue to untouched bars by a horse-shoe magnet, shewn at *plate* 2, *fig*. 15, either single or compound; the bar to be touched should be laid on two other magnets, as in the preceding case; the horse-shoe magnet must be placed on the middle of the untouched bar, with the north end towards that you designed to be the south; you are then to draw it backwards and forwards over the bar five or six times, but be careful when you remove it that it is at that time over the middle of the bar. The same operation is to be used with the other surfaces of the bar.

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* The north ends of magnetic bars are generally marked by a line cut across them, as are also the north ends of horse-shoe or other shaped magnets. Edit.

A small compass needle may be touched by being put between the opposite poles of two magnetic bars; while it is receiving the magnetism, it will be violently agitated, moving backwards and forwards as if it were animated: when it has received as much magnetism as it can acquire in this way, it becomes quiescent.*

TO TOUCH A HORSE-SHOE MAGNET.

Place a pair of magnetic bars against the ends of the horse-shoe magnet, with the south end of the bar against that end of the horse-shoe which is intended to be the north, and the north end of the other bar to that which is to be the south: the contact or lifter of soft iron to be placed at the other end of the bars. In this situation the magnetic fluid, which circulates through the bars, will endeavour to force a passage through the horse-shoe magnet, and thus facilitate the further communication of the magnetic virtue to the horse-shoe magnet: to this end, rub the surfaces of the horse-shoe with a pair of bars placed in the form of a compass, or with another horse-shoe magnet, turning the poles properly towards the poles of the horse-shoe magnet, being careful that these bars never touch the ends of the straight bars, as this would disturb the current of the magnetic fluid, and injure the operation. If the bars are separated suddenly from the horse-shoe magnet, its force will be considerably diminished; to prevent this, slip on the lifter or support to the end of the horse-shoe magnet, but in such a manner, however, that it may not touch the bars; the bars may then be taken away, the support slid to its place, and left there to strengthen the circulation of the fluid.

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* Magnetism is best and most conveniently communicated to compass needles by the two following methods: 1. By a pair of magnetic bars not less than six inches in length. Fasten the needle down on a board, and with a magnet in each hand draw them from the center upon the needle outwards; then raise the bars to a considerable distance from the needle, and bring them perpendicularly down upon the center, and draw them over again. This repeated about twenty times will magnetize the needle, and its ends will point to the poles contrary to those that touched them.

2. Over one end of a combined horse-shoe magnet, of at least two in number and six inches in length, draw from its center that half of the needle which is to have the contrary pole; from a considerable distance draw the needle over it again. This repeated about twenty times at least, and the same for the other half, will sufficiently communicate the power. Edit.

TO MAKE A MAGNETICAL BAR WITH SEVERAL POLES.

Place magnets at those parts where the poles are intended to be, the poles to be of a contrary name to those required; and if a south pole is fixed on one part, the two next places must have north poles set against them; consider each piece between the supporters as a separate magnet, and touch it accordingly.

The difference in the nature of steel with respect to receiving magnetism, is exceeding great, as is easily proved by touching in the same manner and with the same bars two pieces of steel of equal size, but of different kinds. With some sort of steel a few strokes are sufficient to impart to them all the power they are capable of retaining; other sorts require a longer operation; sometimes it is impossible to give them more than a just sensible degree of magnetism.

Steel that is hardened receives a more perfect magnetism than soft steel, though it does not appear that they differ from each other in any thing but the arrangement of the parts; perhaps the soft steel contains phlogiston in its largest pores, while hardened steel contains it in the smaller. Iron and steel have very little air incorporated in their pores; when they are separated from the ore, they are exposed to a most intense degree of heat; and most of the changes to which they are afterwards submitted, are affected in a red-hot state. A piece of spring-tempered steel will not retain as much magnetism as hard steel, soft steel still less, and iron scarce retains any. From some experiments of Mr. *Musschenbroek*, it appears that when iron is united with an acid, it will not become magnetical; but, if the acid be separated, and the phlogiston restored, it will become as magnetical as ever.

In communicating magnetism, it is best to use weak magnets first, and those that are stronger afterwards; but you must be very careful not to use weak after strong magnets.

A magnet can never communicate a greater power than itself possesses, or even of an equal degree; but, as several magnets of nearly an equal degree of magnetism, by being joined together, have a stronger power than either of them singly; in order to impart a stronger magnetic power to a given body A, by means of a weak magnet B, you must first render several bodies, C, D, E, F, &c. weakly magnetic, and then by properly joining C, D, E, F, together, you may communicate to another body, or several bodies, a stronger magnetism; and thus by degrees be able to communicate to A the desired degree of magnetic power.

A magnet loses nothing of its own power by communicating to other substances, but is rather improved thereby.

If bars of iron are heated, and then cooled equally in various directions, as parallel, perpendicular, or inclined to the dipping needle, the polarity will be fixed according to their position, strongest when they are parallel to the dipping needle, and so less by degrees, till they are perpendicular to it, when they will have no fixed polarity; but if, upon cooling a bar of iron in water, the under end is considerably hotter than the upper, and the upper end is cooled first, it will sometimes become the north pole, but not always. If iron or steel undergo a violent attrition in any one particular part, it will acquire a polarity; if the iron is soft, the magnetism remains very little longer than while the heat continues. Lightning is the strongest power yet known in producing a stream of magnetism; it will in an instant render hardened steel strongly magnetical, and invert the poles of a magnetic needle.

Every kind of violent percussion weakens the power of a magnet. A strong magnet has been entirely deprived of its virtue by receiving several smart strokes of a hammer; indeed, whatever deranges or disturbs the internal pores of a magnet, will injure its magnetic force, as the bending of touched iron, wires, &c.

Fill a small dry glass tube with iron filings, press them in rather close, and then touch the tube as if it was a steel bar, and the tube will attract a light needle, &c. shake the tube so that the situation of the filings may be disturbed, and the magnetic virtue will vanish.

But, though a violent percussion will destroy a fixed magnetism, yet it will give polarity to an iron bar which had none before; for a few smart strokes of a hammer on an iron bar will give it a polarity, and by hitting first one end of the bar, and then the other, while it is held in a vertical situation, the poles may be changed. Twist a long piece of iron wire backwards and forwards several times, then break it off at the twisted part, and the broken end will be magnetical.

The pole of a magnet always produces the contrary polarity on a bar to which it is applied: therefore, if two bars fully touched have the poles of the same name joined together, they tend to produce on each other a force of a contrary name to that with which they are endowed; and this effect will diminish the polar force of each bar; consequently, the magnetic force of each longitudinal element of an artificial magnet diminishes as its bulk is increased, and the total force of two magnets fully touched, and of the same length, but unequal in bulk, will be in a less ratio than that of their mass.

If the magnet does not touch the bar, but is held at some distance from it, the phenomena will be the same; but the bar will acquire less magnetism than when it was in contact with the magnet.

Each point of a magnet may be looked upon as the pole of a smaller magnet, tending to produce on the points of the magnet a force contrary to its own. The effect of this tendency will be greater, in proportion to the force of the point, and its nearness to those points on which it acts; and the force of a magnet will depend on the reciprocal action of these points on each other.

Hence, a narrow bar will in general be more powerful than a broader one; and hence also the exterior edges and points of a magnet will have more power than the interior ones of the same bar.

Hence, also, magnets should never be left with two north or two south poles together; for, when they are thus placed, they diminish and destroy each other's magnetism. Magnetic bars should therefore be always left with the opposite poles laid against each other, or by connecting their opposite poles by a bar of iron. The magnetic power is increased in a magnet, by letting a piece of iron remain attached to one or both of its poles. A single magnet should therefore be always thus left.

OF ARMED MAGNETS.

As both magnetic poles together attract a much greater weight than a single one, and as the two poles of a magnet are generally in opposite parts of its surface, in which situation it is almost impossible to adapt the same piece of iron to both at the same time; two soft pieces of iron are applied to the poles of a loadstone, so as to project on one side the magnet; these pieces being rendered magnetic, another piece of iron can be conveniently adapted to these projections, so as to let both poles act at the same time. The magnet in this case is said to be *armed*, the pieces of iron are called the *armature*, the piece of iron that connects the poles is termed the *lifter*. *Plate* 2, *fig*. 14, represents an armed artificial magnet. In a similar manner the loadstone, or natural magnet, is advantageously armed.

To avoid the expense and trouble of the armature, artificial magnets have been made in the shape of an horse-shoe, of which I have already spoken.

Gassendi invented a peculiar kind of armour, by piercing a loadstone in the direction of the axis, and placing a cylinder of iron in the hole, which augmented considerably the force of the magnet.

Here is a straight magnetic bar, the north pole of which supports four ounces. I apply another magnet against it, but so that the north pole thereof is about half an inch from the pole of the other, and it will now sustain near seven ounces.

OF THE MAGNETISM OF THE EARTH.

What has been usually termed the magnetism of the earth, might with more propriety be termed the magnetism of the atmosphere. Even the experiments usually adduced to prove the magnetism of the earth, are full proofs that it is an aerial influence; as you will perceive by the account I am going to give you of the experiments brought in support of the earth's magnetism.

Mr. *Savery* has adduced several instances to shew the force and action of the earth's magnetism; among others, that it will support small pieces of iron. He hung up a bar of iron, about five feet long, by a loop of small cord at the upper end, and then carefully wiped the lower end, and the point of a nail, that there might be no dust or moisture to prevent a good contact; then holding the nail under the bar with its point upward, he kept it close to the bar, holding only one finger under its head for the space of thirty or more seconds; then withdrawing his finger gently downwards, that the nail might not vibrate; if it fell off, he wiped the point as before, and tried some other part of the plane at the bottom of the bar. If the ends are similar, and the bar has no permanent virtue, it is indifferent which end is downwards; if it has an imperfect degree of polarity, one end will answer better than the other.

The upper end, A, of a long iron rod, which has no fixed polarity, will attract the north end of a magnetic needle; the under end, B, repels the north end of the needle; invert the iron bar, and the end B, which is now the upper one, will attract the north pole of the needle it repelled before. The case is the same, if the bar is placed horizontally in the magnetic meridian, the end towards the south will be the north pole.

The explanation of this curious phenomenon is easily deduced from the foregoing observations; for, since in these northern parts, the earth is possessed of a south magnetic polarity, the lowest part of the iron bar, by being nearest to it, must acquire the contrary, namely, the north polarity; the other extremity of the bar becoming a south pole.

It follows, likewise, and it is confirmed by actual experiment, that in the southern parts of the earth, the lowest part of the bar acquires the south polarity; that on the equator, the bar must be kept horizontal, in order to let it acquire any magnetism from the earth; and that, even in these parts of the earth, the most advantageous situation of the bar is not the perpendicular, but that a little inclined to the horizon. In short, in every part of the world it must be placed in the magnetical line, *viz.* in the direction of the dipping needle. If the iron bar, instead of being kept in the magnetical line, be placed in a direction perpendicular to it, then it will acquire no magnetism, because in that situation the actions of both poles of the earth upon each extremity of the bar are equal. If, instead of the above-mentioned two directions, the bar be placed in any other position, then it will acquire more or less magnetic power, according as it approaches nearer to the former or to the latter of the said two directions.

Iron bars of windows, which have remained long in a vertical position, acquire a fixed polarity. Mr. *Lewenhoek* mentions an iron cross, which had acquired a very strong polarity. Mr. *Canton* proposed to make artificial magnets without the assistance of natural ones; but in this he was mistaken, for his poker and tongs were natural magnets, and had their verticity fixed by being heated and cooled in a vertical position; and an iron or steel bar, though without a verticity, while it remains in that position exerts a polarity, and is able to communicate a fixed verticity to the small bar, and is, therefore, for the time a natural magnet. And further, every iron bar, from the largest size to a sixpenny nail, will exert this power when treated as above-mentioned. But how this power is raised so soon to a degree greatly exceeding that which communicated it, we do not know; nor is it more easy to account for the facility with which the magnetic power is withdrawn by a friction contrary to that which gave it.

OF THE DIRECTIVE PROPERTY OF MAGNETS.

Let an iron rod be exactly ballanced and suspended on a point, so as to revolve in a plane parallel to the horizon; communicate the magnetic virtue to this rod, and the extremity will be always directed towards the north.

Here is an untouched magnet, I place it on a point, and you may observe that I can make it rest in any given situation; I shall communicate the magnetic virtue to it, and you will then find it no longer indifferent as to its situation, but it will fix upon one in preference to any other, one end always pointing to the north.

Whenever a magnet can move itself freely, as if it be suspended by a fine thread, or if it be made to float on water by means of a piece of cork, or if it be ballanced on a point, provided it be not disturbed by the vicinity of iron; it will always place itself so as to direct its north pole towards the north, and the south pole towards the south.

The directive power of a touched needle is of the greatest importance to mankind; it enables the mariner to traverse the ocean, and thus unites the arts, the manufactures, and the knowledge of distant countries, together. The surveyor, the miner, and the astronomer, derive many advantages from this wonderful property.

The *mariner's compass* consists of three parts, the box, the card or fly, and the needle.

The card is a circle of stiff paper representing the horizon, with the 32 points of the compass marked on it; the magnetical needle is fixed to the under side of this card; the center of the needle is perforated, and a cap with a conical agate at its top is fixed in this perforation; this cap is hung on a steel pin, which is fixed to the bottom of the box, so that the card hanging on the pin turns freely round its center; one of the points being, from the property of the needle, always directed towards the north pole. The box which contains the card and needle is a circular brass box hung within a square wooden one, by two concentric rings called jimbals, so fixed by cross centers to the two boxes, that the inner one shall retain an horizontal position in all motions of the ship. The top of the inner box has a cover of glass, to prevent the card from being disturbed by the wind.* Before the compass was invented, the navigating of ships was a tedious and precarious operation, and seldom performed out of sight of land; but this instrument enables the mariner to travel over the seas almost in as direct and true a tract, as the land carrier directs his carriage in a well-beaten road.

It has been already observed, that the ancients do not seem to have been acquainted with the directive power of the magnet. The only thing that seems capable of being mistaken for some such knowledge, is what *Jamblichus* tells us in his life of *Pythagoras*, "That *Pythagoras* took from *Abaris*, the Hyperborean, his golden dart, without which it was impossible for him to find his road." But the authority of the writer, as well as the obscurity of the passage, prevents any conclusion being drawn from it.

Paul, the Venetian, is said to have introduced the use of the compass in 1260; but this is said not to have been his own invention, but borrowed from the Chinese. *P. Gaubil* says, the directive power of the needle was known to the Chinese as early as the year A.D. 223, under the dynasty of *Haz.* But the Abbe *Renaudot*, in his Dissertation on the Stone, when the Mahomedans went first to China, has adduced strong reasons to prove, that the Chinese knew nothing of the mariner's compass till it was introduced there by the Europeans. *Vertomanus* affirms, that A.D. 1500, he saw an East Indian pilot direct his course by a compass, framed and fastened like those used in Europe; but this must be received with some caution, as M. *Barlow*, in 1597, says, that in a personal conference with two East Indians he was told by them, that instead of our compass they made use of a magnetical needle of six inches or longer, set upon a pin in a dish of white China earth filled with water; that in the bottom of the dish they had two cross lines to mark the four principal winds, and that the rest of the divisions were left to the skill of the pilot. But to return to Europe, Mr. *Perrault*, in his parallel between the ancients and the moderns, has cited some verses of *Guyot de Provins*, who wrote in 1180, which shew distinctly, that the mariner's compass was known in the South of France at that time.

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* This is called simply the *steering compass*; with the addition of sights, divided circles, &c. for observing azimuths and amplitudes of the heavenly bodies, it is called the *azimuth compass*.

EDIT.

By most writers the invention of the compass is ascribed to *Flavio Goin*, of Analsi in Campance, who lived about the year 1300; and he is said to be the first that applied it to navigation in the Mediterranean.

Mr. *de Lalande* informs us, that in *Le Tresor de Brunet*, a manuscript in the French king's library, there is a passage which proves that the compass was made use of about the year 1260.

Here however it may be observed, that though a magnet, which has only two poles, will always, when freely suspended, place itself in the magnetic meridian, or in the same plane with other good magnets; yet when a magnet has more than two poles, these may be so situated that the magnet will not traverse, that is, will have no directive power.

Thus, suppose an oblong magnetic needle to have a north polarity equally strong at each end, and a south polarity in the middle; it is plain, that as each has an equal tendency towards the north, neither of them can be directed towards the north in preference to the other; consequently, the needle cannot traverse. Though this case very seldom occurs, yet there are many others where a needle, when fixed to a card on which the points of a compass are drawn, may occasion considerable errors; this has been clearly proved by Dr. *Knight* and Capt. *Greaves*. Mr. *R. Walker*, of Jamaica, has also clearly proved, that the only proper shape for magnetic compass needles, is that where the line of direction is in the edge of the bar; each end of the bar should be also pointed.

OF THE VARIATION OF THE COMPASS.

Though the north pole of the magnet is, in every part of the world, directed nearly towards the north, yet it very seldom points exactly thereto, and consequently the south pole of the magnet seldom points towards the south. In other words, the magnetic meridian seldom coincides with the meridian of the place, but generally varies from it some degrees eastward or westward.

This variation is different in different places on land as well as at sea, and is continually varying in the same place. For instance, the variation is not the same in London as at Paris, or at the Cape of Good Hope; and the declination at London, or at any other place, is not the same now as it was twenty years ago.

This variation is always reckoned from the north; that is, if the north end of a needle vary to the east of the north, the variation is said to be easterly;

and if it vary to the west, the variation is said to be westerly.

The uncertainty of the quantity of this variation in different parts of the world is a great impediment to the perfecting of navigation; and philosophers have earnestly endeavoured to investigate its cause, and, if possible, to correct the errors it occasions.

Though the directive power of the compass was applied to the purposes of navigation in the fourteenth and fifteenth century, it does not appear, that there were any apprehensions during that time of its pointing otherwise than due north and south.

The variation of the compass is said to have been first discovered by *Columbus*, the latter end of the fifteenth century. But the first person who discovered that it was real, and was the same to all needles in the same place, is generally allowed to be *Sebastian Cabot*. This was about the year 1497.

After the variation was discovered by *Cabot*, it was thought, for a long time, to be invariably the same at the same places in all ages; but Mr. *Gellibrand*, about the year 1625, discovered, that it was different at different times in the same place.

From successive observations made afterwards it appears, that this deviation was not a constant quantity, but that it gradually diminished, and at last, about 1657, it was found, that the needle pointed due north at London, and has ever since been increasing to the westward of the north. So that in any one place the variations have a kind of libratory motion, traversing through the north to unknown limits eastward and westwards. The present variation at London is about two points, or 23 degrees west of the north.

Dr. *Halley* supposed, that the earth has within it a large magnetic globe, not fixed within to the external parts, having four magnetic poles, two fixed and two moveable, and by this he has endeavoured to account for the phenomena of the needle. His application of this theory to facts is in many respects inadequate, in all laboured and unnatural. Mr. *Euler* has shewn, that he can with two magnetic poles placed on the surface of the earth, account for all the phenomena as well as Dr. *Halley* with four; but his theory has also various imperfections.

The variation of the needle may be illustrated by placing several touched needles round a magnetic bar, see *plate* 2, *fig*. 12. Now, if the earth be a great magnet, or if it have only a magnetic atmosphere, it is clear from this experiment, that magnetic needles placed on its surface would have different directions in different places, which is conformable to experience; and the apparent irregularities in the variation of the needle must be occasioned by the situation of the magnetic poles of the earth.

If the magnetic poles agreed with those of the earth, there would be no variation, and the magnetic needle would point to the true north and south. If the axis of the magnetic poles passed through the center of the earth, it would be easy to assign the quantity of the variation at every place; but as this is not the case, to account regularly for the variation, it is necessary to know the exact situation of the magnetic poles of the earth, their number, force, and distance from the real poles; whether they shift their place, and if they move, the quantity of motion every year.

OF THE DIURNAL VARIATION OF THE NEEDLE.

About the years 1722 and 1723, Mr. *George Graham* made a number of observations on the diurnal variations of the magnetic needle. In the year 1750, Mr. *Wargentin* took notice of the regular diurnal variation of the needle; and also of its being disturbed at the time of an aurora borealis. About the latter end of the year 1756, Mr. *Canton* began to make observations on the variation, and in 1759, communicated several valuable experiments to the Royal Society.

The observations were made by him for 603 days; on 574 out of these the diurnal variation was regular. The absolute variation of the needle westward was increasing, from about eight or nine o'clock in the morning till about one or two in the afternoon, when the needle became stationary for some time; after that, the variation westward was decreasing; and the needle came back again to its former situation in the night, or by the next morning.

The diurnal variation is irregular when the needle moves slowly eastward in the latter part of the morning, or westward in the latter part of the afternoon; also when it moves much either way after night, or suddenly both ways in a short time. These irregularities seldom happen more than once or twice in a month, and are always accompanied with an aurora borealis. The diurnal variation in the months of June and July is almost double that of January and December.

Mr. *Canton* supposes, that the diurnal heat of the sun acts upon the magnetic parts of the earth, or rather upon the magnet included in the earth. But Mr. *Æpinus* has shewn, that this supposition is inadmissible, because agreeable to the hypothesis the magnetic nucleus must be very profound, and it is well known, that the solar heat does not penetrate to very great depths; there are caves at no great distance from the surface of the earth, in which a thermometer remains always at the same height. The diurnal heat does not penetrate even these, there is therefore no probability of its effects extending to still greater depths.

OF THE DIP OF THE NEEDLE.

If a needle, which is accurately ballanced and suspended, so as to turn freely in a vertical plane, be rendered magnetical, the north pole will be depressed, and the south pole elevated above the horizon: this property is called *the inclination* or *dip of the needle.* As it is very difficult to ballance a needle accurately, the poles are generally reversed by a magnet, so that its two ends may dip alternately, and the mean of the two is taken.*

This property was discovered by *Robert Norman*, about the year 1576. I shall give the account of the discovery in his own words:

"Having, says he, made many and divers compasses, and using always to finish and end them before I touched the needle, I found continually that after I had touched the yrons with the stone, that presently the north point thereof would bend or decline downwards under the horizon in some quantity; insomuch, that to the flie of the compass, which before was made equal, I was still constrained to put some small piece of wax in the south part thereof, to counterpoise this declining, and to make it equal again.

"Which effect having many times passed my hands without any great regard thereunto, as ignorant of any such property in the stone, and not before having heard nor read of any such matter; it chanced at length that there came to my hands an instrument to be made, with a needle of six inches long, which needle after I had polished, cut off at just length, and made to stand level upon the pin, so that nothing rested but only the touching of it with the stone: when I had touched the same, presently the north part thereof declined down in such sort, that being constrained to cut away some of that part to make it equal again, in the end I cut it too short, and so spoiled the needle wherein I had taken so much pains.

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* The dipping needle represented at *plate* 2, *fig.* 7, is one of the commonest and smallest kind. The most complete and accurate dipping or rather *universal magnetic needle*, shewing at the same time the horizontal and vertical directions of the magnet, was contrived by the late ingenious Dr. *Lorimer*, a philosopher, who, among the moderns, has perhaps made the greatest variety of experiments and discoveries in the science. See his Concise Essay on Magnetism, 4to. 1795. EDIT.

"Hereby being stroken into some cholar, I applied myself to seek further into this effect, and making certain learned and expert men (my friends) acquainted in this matter, they advised me to frame some instrument, to make some exact trial, how much the needle touched with the stone would decline, or what greatest angle it would make with the plane of the horizon." Thus far Mr. *Norman.*

The dip is said to be subject to a variation. At this time in London it is about 72 degrees; from some late observations it appears to diminish about fifteen minutes in four years. The nature of this phenomenon is pleasingly illustrated by carrying a small dipping needle from one end of a magnetic bar to the other; when it stands over the south pole, the north end of the needle will be directed perpendicularly to it; as the needle is moved, the dip will grow less, and when it comes to the magnetic center it will be parallel to the bar; afterwards the south end will dip, and the needle will stand perpendicular to the bar, when it is directly over the north pole.*

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* *Plate* 2, *fig.* 17, represents an instrument called a *magnetometer*, or an instrument to ascertain the comparative strength of magnetical bars. A is a brass quadrant divided into 90°; B, a magnetic needle vertically suspended and ballanced; C, a brass base divided into inches and tenths. The bars to be examined are laid on the base, and their respective powers are shewn by the distance of the ends of the bars on the base from 0 on the arc, and

OF THE INFLUENCE OF THE AURORA BOREALIS ON THE MAGNETIC NEEDLE.

Messrs. *Wilcke* and *Van Swinden* have clearly proved, that there is a connexion between the aurora borealis and the magnetic needle; they have shewn it to be so evident, so general, and so constant, that no one, who examined the affections of the one and the other with attention, could have any doubts on the subject. It remained, however, for Mr. *Dalton*[*] to give a complete and satisfactory account of this connexion, and it is with great pleasure I take this opportunity of recommending his work to your attentive perusal.

From various observations he has demonstrated, 1. When the aurora appears to rise only about 5° 10′, or 15° above the horizon, the needle is very little disturbed, and often insensible. 2. When it rises up to the zenith, and passes it, there never fails to be a considerable disturbance. 3. This disturbance consists in a regular oscillation of the horizontal needle, sometimes to the eastward, then to the westward of the mean daily position, in such sort, that the greatest excursions on each side are nearly equal, and amount at Manchester to about half a degree on each side. 4. When the aurora ceases, or soon after, the needle returns to its former station.

From these facts alone, says Mr. *Dalton*, independent of other observations, we cannot avoid inferring, that there is something magnetic constantly

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the number of degrees on the arc up to which the needle, B, is repelled.

Collections of the several magnetical articles, part of which are shewn in *plate* 2, to illustrate the general principles of magnetism, are selected and packed by us in cases, and which form either to the lecturer or student a new and useful collection of curious instruments. EDIT.

[*] Meteorological Observations and Essays, by *John Dalton*, 1793.

in the higher regions of the atmosphere, that has a share at least in guiding the needle; and that the fluctuations of the needle, during the aurora, are occasioned by some mutations that then take place in this magnetic matter in the incumbent atmosphere.

OF THE SIMILARITY BETWEEN ELECTRICITY AND MAGNETISM.

The powers of magnetism, like those of electricity, are excited and separated by friction. This effect is wonderful in both, but more so in magnetism, where two powers, naturally attracting each other, remain separated in the steel bar for many years, and yet they may be reduced to their natural state by the friction of two other magnets, acting in contrary order to that by which the poles were originally separated.

Magnetism and electricity act powerfully at corners, edges, and points.

Magnetism may be communicated to a small steel needle, by passing the discharge of a large electrical battery through it.

The discharge of an electrical battery through a small magnetic needle will sometimes destroy the magnetism, and sometimes invert the poles of the magnet. Similar effects have been produced by lightning.

OF THE THEORY OF MAGNETISM.

Here, as in other parts of natural philosophy, we must content ourselves with mere conjecture. Of the various hypotheses that have been formed to account mechanically for the phenomena of magnetism, that of Mr. *Prevost** is undoubtedly the best; but as it depends on a knowledge of Mr. *le*

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* *Prevost* de l'Origine des Forces Magnetiques a Geneve, 1788.

Sage's mechanical system of the universe, it will be impossible for me to lay it before you in a satisfactory manner; you must therefore be contented with a very imperfect sketch thereof.

HYPOTHESIS.

There exists in and about our globe a very subtile fluid, possessing the following properties:

1. It is expansive, and consequently discrete.

2. The molecules of this fluid are formed by the union of two kinds of elements, A, B, united by affinity.

3. The elements of the different kinds have a greater tendency to each other than those of the same kind.

4. That excepting the preceding property, these attractions follow the same laws as universal gravitation.

5. This fluid has an affinity with the particles of iron, and which probably acts only at contact, or when nearly in contact. This fluid is decomposed by iron, and seldom by any thing else.

The foregoing properties of the magnetic fluid may be all mechanically explained on the principles of Mr. *le Sage*.

To explain the magnetic phenomena of the earth, it is sufficient to suppose that one aliment of the magnetic fluid is furnished by nature in greater abundance in one hemisphere than the other; or that a small portion thereof be decomposed by some of the causes perpetually acting in nature, by which means the terrestrial globe is maintained in a charged state, having a greater abundance of one element in one hemisphere than in the other. This accumulation may principally exist in the atmosphere.

On considering that the aurora borealis, the zodiacal light, electricity, and heat, all in some measure affect the magnetic needle, there seems ground for supposing that one or other of the elements of the magnetic fluid is furnished by the solar rays.

When we consider the extent occupied by the magnetic fluid, we are naturally led to inquire whether its effluvia course incessantly over land and sea, only to turn here and there a mariner's compass? Being assured that God governs by a long subordination of second causes; that he not only employs a concurrence of causes to produce one effect, but likewise produces various effects from one and the same cause; we may safely answer, that there are other uses of the magnetic effluvia, besides those we discern. Here again, as in every other part of philosophy, we have a further confirmation of the littleness of human knowledge, and see how much pains God has taken, so to speak, *to hide pride from man.*

LECTURE LI.

ON METEOROLOGY.

There is scarce any subject in which mankind feel themselves more interested, than in the state of the weather, that is, in the temperature of the air, the influences of wind, rain, &c. It forms a principal topic of common conversation. By the weather, the traveller endeavours to regulate his journies, and the farmer his operations; by it plenty and famine are dispensed, and millions are furnished with the necessaries of life. It is intimately connected with the health of the human body, and with every part of natural history, and more particularly with agriculture. You will therefore find this branch of philosophy peculiarly interesting; the more so as it will lead you to consider the great operations in nature.

"Here you may see and admire the changes in the elements, which present us with all that is great and wonderful in nature, and which, with a variety little less than infinite, work together for the good of man, and the preservation of the world."

I have long since observed to you, how improperly the science of natural philosophy has been treated by its most zealous advocates and ablest professors; it is high time for them, after so much labour in vain, to return to the point from whence they should have set out, and now begin to consider the great agency of the elements. It is by this agency, that all the phenomena we perceive are performed; by it the growth of plants, the life of individuals, are supported and preserved; by it the planets are maintained in their respective situations, and made to revolve in their orbits.

"There is no hope in the present mode of philosophizing, but of seeing experiments varied, and facts multiplied; and they may be thus multiplied and varied to eternity without advancing us one step towards a knowledge of the causes operating in nature. The indefatigable experimentalist may proceed for ever, and flounder like the mole in the dust he raises about himself; but by continually heaping up of facts, or making experiments, he will never be able to trace either the nature or design of the operations carried on in this system of things." For the universe is a system, in which all the parts are connected and related, and matter, as a part of the created world, has motion; but he who would understand the nature of motion, by considering motion abstractedly, as is the case with many modern philosophers, is studying motion from that which has no motion belonging to it. There is, as I have before observed to you, no insulated fact in nature;

they are all systematic, or mechanical, having a double reference; as effects to their causes, and as causes to their effects. The material world is an immense body, composed, like our own, of an infinite number of parts, so interwoven together, as to unite in one common center. It is the business of philosophers to point out these connexions, and to explain when they appear to us as separated, and thus lead us to that principle of unity which harmonizes and connects all the works of creation.

But alas, you find the philosopher continually losing sight of the true construction of nature, and endeavouring to build systems upon matter independently considered, " upon which he can only raise such a world as never did nor can exist, being as empty and absurd, as it is arbitrary." " You find physicians treating of the nature and causes of diseases, of blemishes, of preternatural appearances in the body; but wholly indifferent, and altogether inattentive to the proceedings of the healthy economy: you will find an hundred dissertations on fevers, for one upon life. The action of stimuli, and the irritability of the living fibre, have been the subjects of many ingenious discussions; the regular and uniform action of the fibre, but of few. It is the same with philosophy; we have treatises on light, as separated and divided by the prism; on heat, as measured by the thermometer; but none on that ocean of the solar fluid, in which all bodies are as it were immersed; none upon the various influences of the sun, upon which the natural life, and the activity of all things in the natural world depend.*

If we look into artificial nature, we shall every where find a want of known agents. Hence the variety and changes of opinion with respect to a great number of phenomena that are observed in our laboratories; although we can there multiply and vary the processes, and thus subject our conjectures to experiment; but the phenomena being all on a small scale, we are often but very little struck with circumstances, that may in themselves be very important, and which are daily perceived. We are diffident of the exactness of our measures and weights; we suspect some foreign influence from the vessels used, from the disparity in substances of the same kind and name, or from some unknown action of the air and vapour; and yet, unless we have learned not to be satisfied with vague conjecture, we seldom attend to the notices which result from the imperfections and inaccuracies of our theories. But in the laboratory of the atmosphere, all the phenomena are carried on upon a scale proportioned to their importance among the operations of nature, which can be disturbed by nothing foreign to these operations, without producing some characteristic phenomena; every thing has a reference to the vessel itself, *i. e.* to the surface of our globe, whose distinct parts, as minerals, vegetables, and animals, offer masses perpetually changing; here, therefore, the disagreement of theory with facts must give us great and important lessons.*

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* *Young*'s Essay on the Powers and Mechanism of Nature.
Jones's Physiological Disquisitions.
Adams's Dissertation on the Barometer, &c.

If you, however, compare attentively meteorological phenomena with our physical measures, the barometer, the thermometer, hygrometer, &c. you will find yourself unable to reduce them to any law, that can be expressed by the range of these instruments: which shews more evidently than any thing that can be seen in our laboratories, the necessity of admitting other combinations than those that are known, and even perhaps other ingredients.

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* *De Luc*, Idees sur la Meteorologie, a work that should be fully considered by all who mean to understand the subject, and to which I am indebted for a great part of the Lectures on Meteorology.

The meteorological phenomena, whose causes we have yet to explore, are those that are most common and the most important to terraqueous physics. They are changes of heat independent of seasons and latitude, those of winds, and the variations in the heights of a local barometer; the vicissitudes of rain and fair weather; aerial electricity and magnetism; the relations of the state of the air to our sensations; the small connexion we find between vegetation (as well in general, as for certain particular products), and the different remarkable characters of the seasons. All these grand lines in the operations of nature on our globe are to us, with respect to the producting causes, as a sealed book.

These observations on the chemistry of nature are by no means designed to lessen your esteem for that of our laboratories, which is certainly one of the principal sources of all the true science we possess. They are designed to shew you, that the smallest meteorological phenomena should be studied with as scrupulous an attention, as that we pay to the modifications of a little air in our close vessels; for it is these phenomena which should guide us in our researches into the nature of the latter.

In the atmosphere every cause produces its effects: the subtile fluids are there distributed according to their natural tendencies; and can form or destroy themselves differently, in different times, different soils, different climates: the winds, which have seldom been considered, but as more or less violent, warm, or humid, may, with respect to these fluids, answer more important purposes than what have yet been attributed to them. In a word, great general causes act in the atmosphere from which our confined air is secluded. It is therefore only by letting meteorology and chemistry go hand in hand, that we can hope to be secure from error in either pursuit, or be enabled to make advances towards real knowledge.

Our researches into the nature of these interesting objects will be ever vague, and of course attended with but little success, till we have some certain theory on the nature of expansible fluids, and in general of all physical agents. Here it may be proper to observe, that we commonly join to physical laws the idea of their being an explanation of the phenomena; but this notion is erroneous, for all physical laws, not excepting even those of gravity, are only generalisations. We are now acquainted with many phenomena, where the real agents manifest themselves, and whose laws flow from the nature of these agents: it is to such as these only that the idea of a physical explanation can be attached. Thus, to assign to phenomena a real and determined agent, acting in a certain manner, and from which certain effects are the natural consequences; and to shew that the laws of these phenomena correspond thereto, is really to explain the phenomena. Now we know phenomena enough, thus connected with real causes, to enable us by analogy to extend very far the real links that connect effects one with the other in nature; remembering always to consider true agents as being more and more general, the further they are removed from us; or subordinate, as they approach us. These are the proper objects to occupy the attention of a rational philosopher, as they alone can form the foundation of rational physics, one that will give us efficacious aid in our experimental researches. What would become of practical mechanics, if in elementary mechanics there was no system of its agents, no laws previously determined, which they follow when they operate? And yet, though all is action in nature, philosophers scarce think of looking for the true agents.

Among the means of advancing our knowledge in meteorology, are the instruments that have been contrived to ascertain the variations in the weight of the atmosphere; its changes with respect to temperature; the degrees of humidity, &c. If every one who is in posession of meteorological instruments would keep a diurnal register of their state, and of the corresponding phenomena of the atmosphere, and transmit the result of his observations to the public, he would contribute more to the advancement of this branch of science than he might at first imagine. While he was amusing himself, and gratifying curiosity, he would be promoting knowledge, and probably procuring benefits for posterity. Let no one suffer the apparent improbability of success to discourage him from the attempt. Remember that science advances by slow and gradual steps, that its progress depends on the cultivation of the mind, the acquisition of facts, the removal of obstacles, and the exertion of individuals: the present is ever pregnant with the future, though the connexion between them can only be found by long attention and diligent observation. A register for preserving what no memory can retain, becomes an authentic document, a reference from which facts may be combined and compared, and thus one of the purest sources of practical knowledge. To indulge ends so rational to as great an extent as the human powers can reach, and with as much enjoyment as the human mind can bear, Divine Providence hath appointed the means whereby each man's small stock of knowledge and truth may be communicated to others without loss to himself; and further, how it may be placed in a common treasury for every man to draw from thence whatever his occasions or inclinations may require. These ends are known to be accomplished, the first by speech, the latter by writing and publishing what is written.

It may be observed in general, that meteorological phenomena, like all the durable motions of the universe, depend upon a circulation of matter. Here it is principally carried on by changing of water into a new form, and a regeneration of it again into its primitive form. It goes off from the surface of the earth in the form of a rare invisible expanded vapour; in the atmosphere, its state is changed, and from that of vapour to an aeriform fluid; by some unknown cause it is again changed into mists and clouds, it is then gathered into drops when it falls, and in this form it returns to the place from whence it came, to take its turn once more in the common course of evaporation, and be again and again circulated to the great promptuary of the world.

The principal objects therefore of inquiry are, 1. In what manner the atmosphere is supplied with humidity? 2. What causes and what prevents invisible humidity from being formed into clouds? And, 3. What occasions and prevents visible clouds from being precipitated into rain? That is, to know the various ballancings of the clouds, and learn how such ponderous materials are suspended in the air; and how the waters are bound up in the thick clouds.

As one of the principal means of answering these inquiries are the instruments used to discover the changes in the atmosphere, I shall first describe these, and then proceed to give you some account of meteorological phenomena. The instruments in general use are, 1. A barometer; 2. A thermometer; 3. An hygrometer; 4. A rain-gage; 5. An electrometer.

OF THE BAROMETER.

In treating of the barometer, I shall have only to enlarge on some circumstances that were but slightly noticed, when I explained this instrument to you in my Third Lecture. The barometer, as I there shewed you, consists of a straight glass tube, about thirty-two inches long, open at one end and close at the other; this tube is first filled with mercury, and then inverted in a bason of the same fluid, by applying a finger to the open end, so as to prevent any air from entering the tube; when the open end of the tube is immerged beneath the surface of the mercury in the bason, the finger is withdrawn; the tube being now set upright, the mercury descends, leaving the top of the tube, and subsiding till it has attained a certain distance from the surface of that in the bason; this is more or less, according to the state of the air at the time of making the experiment. The tube is then fixed to a frame with a scale annexed, to shew at all times the height of the mercurial column.

From the method of filling the tube, the air is excluded from the top of the column, or that part of the tube above the surface of the mercury in the tube. The external air presses upon the quicksilver in the cistern, and sustains, by its pressure in a contrary direction, a column equal in weight to itself. For it is evident, that the mercury endeavours to descend with a force equal to that by which its descent is prevented. In other words, the pressure of the atmosphere on a given surface is equal to the weight of a column of mercury, whose base is the given surface, and height equal to that of the atmosphere. The height of the mercury is therefore an adequate measure of the weight or pressure of the air upon a surface equal to the base of the tube containing the mercury.

The truth of this reasoning I have confirmed by several experiments, exhibited in my Third Lecture; you there saw, when a barometer was placed under a receiver, that in proportion as the air was exhausted from the surface of the mercury in the bason, the column in the tube descended till at last they were nearly on the same level. The barometer-gage exhibited the reverse of this experiment, for you there saw the mercury rise in the tube in proportion as the air was exhausted therefrom, the open air pressing at the same time upon the surface of the mercury in the bason. What is thus exhibited by our instruments is confirmed by nature, for the higher we ascend in the atmosphere the shorter is the column of mercury.

The barometer with a straight tube, as originally contrived by *Torricellius,* is preferable to all the subsequent variations in its form. When it was found that the different heights of the mercury in the barometer were in some measure connected with the state of the weather, the philosopher and artist endeavoured to vary the form of the instrument; hence a variety of constructions more or less accurate, according to the views of the inventors, and the distance to which they removed the barometer from its original simplicity.

They thought, that by augmenting the scale of the barometer, and thus rendering the variations of the mercury more sensible, they should sooner discover the minute changes of the atmosphere, and the causes which occasioned them: unfortunately, by altering the construction of this instrument, they only multiplied errors, and rendered it less capable of answering the purposes for which it was designed. Some of these forms may appear more elegant than the plain barometer, but none of them can be depended upon for keeping an accurate register of the weather, or for observing the extent of the variation thereof in any given situation, or comparing the different changes at one place with corresponding ones at another. Hence it is necessary to point out to you what is requisite to constitute a good barometer.

SOME OF THE PRINCIPAL REQUISITES OF A GOOD BAROMETER.*

1. It is requisite that the height of the column of mercury be altered by no other causes but the changes that arise from the pressure of the air; and that these changes be truly indicated.

2. That the variations in the height of the column be ascertained by a known measure.

3. That the column of mercury be susceptible of the smallest alterations in the weight of the air.

In order that the column of mercury in the tube may be affected by no other cause than the pressure of the air, it is absolutely requisite that the upper part of the tube, and the mercury itself be entirely freed from the air; for, if there be any air between the upper surface of the column of mercury and the sealed end of the tube, it will be the source of many errors and much irregularity. The included air will act as a counterpoise against the weight of the atmosphere, and to a certain degree counteract its pressure; and, therefore, render the indication of the instrument uncertain and erroneous. This included air, being also often combined with humidity, expanded by heat or contracted by cold, acts differently at different times: the only method of preventing these errors, and perfectly excluding the air from the barometer, is by boiling the mercury in the tube; an operation which is carefully performed in all the best instruments.

TO BOIL THE QUICKSILVER IN A BAROMETER TUBE.†

Choose a tube not less than three feet long with a bore about three or four twentieths of an inch in diameter, but not more; and that it may be sufficiently strong, it should be nearly as thick on all sides as the diameter of the bore. Let this tube be nicely sealed or closed at one end, and as clean as possible; fill the tube with pure mercury to within two inches of the top, and then hold it with the sealed end lowest in an inclined position over a chafing-dish of burning charcoal, placed near the edge of a table, in order that all parts of the tube may be exposed successively to the action of the fire, by moving it obliquely over the chafing-dish. The sealed end is to be first gradually presented to the fire; as soon as the mercury becomes hot, the internal surface of the tube will be studded with an infinite number of air-bubbles, giving the mercury a kind of grey colour; these increase in size by running into one another, and ascend towards the higher parts of the tube, where meeting with a cooler part of the fluid, they are condensed, and nearly disappear. In consequence, however, of successive emigrations towards the upper parts of the tube which are successively heated, they finally acquire a bulk which enables them in their united form entirely to escape. When the first part of the tube is sufficiently boiled, move it onward by little and little through the whole length of the tube. When the mercury boils, its parts strike against each other, and against the sides of the tube with such violence, that a person unacquainted with the operation naturally apprehends the destruction of his tube.

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* See my Dissertation on the Barometer and Thermometer, 1790.

† *De Luc's* Recherches sur les Modifications de l'Atmosphere.

The great advantages that result from this operation appear to be these: the whole body of the mercury, and the interior surface of the tube are hereby freed from all the minute and imperceptible particles of dust and moisture which they generally contain, and of the little atmospheres that are seen to surround them; which, during the tumultuous motions of the mercury, are visibly driven up towards its surface, and expelled. The tube and the mercury are deprived likewise of all the air that can be expelled from them, and particularly from the surface of the former, by the violent heat and agitation of boiling quicksilver. As that heat too is a determinate or fixed quantity, its effects in expelling the air from different tubes will be nearly equal; so that, though some small portion of air may still be left in them, there can be no difference in the quantity of it remaining in different tubes thus uniformly treated. Accordingly, the barometers thus prepared not only stand higher than those which have not undergone this process; but at the same time they pretty accurately correspond with each other.

M. *de Luc* observes, that the greatest part of the air which is expelled during the process, proceeds from the internal surface of the tube, where it seems to have formed a thin stratum or lining of air, which cannot be dislodged from thence by the mercury introduced into the tube in the common manner, but requires the violent heat and agitation of boiling quicksilver to detach it. But it is very remarkable, that, after this aerial coating has been once effectually separated and expelled, if the tube be emptied and some other, even cold mercury, be introduced into it, the barometer thus extemporaneously made, will be nearly as perfect or as free from air as before. It will stand nearly as high as it did when it contained the mercury that had been boiled in it; if the same process be now repeated, it will not be studded with bubbles of air, as in the former operation; when the mercury has been completely boiled, the tubes may be cut off to their proper length by a file.

When tubes are well boiled, the mercury generally remains suspended at top, and will not descend to its proper level without shaking the tube to bring it down.

That the changes in the height of the mercurial column may be truly ascertained, it is necessary to know at all times the exact distance of the surface of the mercury in the tube from the surface in the reservoir or cistern.

The first point of the measure must commence from the surface of the mercury in the cistern; but this surface is variable; for, when the mercury descends, a quantity of it falls into the bason, and raises the surface thereof, and on the contrary, when it rises, a quantity is taken out of the cistern, and the surface thereof is lowered. The scale of inches to the barometer is fixed; but the surface of the mercury in the cistern from which it originates is continually varying. To remedy this evil, it is necessary that the lower surface should be always kept at the same height from divisions on the scale affixed to the instrument. This is effected by means of a floating gage, which was first applied to the barometer by my Father, though others have, since his time, assumed the merit to themselves. By means of the floating gage, the same screw that renders the barometer portable, regulates the surface of the mercury in the cistern, so that it is always at the place from whence the divisions on the scale commence. This gage is never applied to the common portable barometers, but only to those of the best kind.

Another circumstance necessary to be attended to in very accurate observations, is the effect of heat and cold on the barometer, as by these the mercurial column is either dilated or contracted; for, as all bodies expand and occupy larger spaces when their temperature is increased, the mercury in the barometer will, when heated, be specifically lighter, and will consequently ascend from that cause, though the pressure of the air should remain unchanged; and therefore, in order to know accurately the effect of the air's pressure on the barometer, it is necessary to correct the height by the addition or subtraction of a quantity equal to the influence of the temperature of the air thereon. In some cases, a scale of correction is applied to the thermometer accompanying the barometer, and which is indeed a necessary companion to it.

2d. Condition. That the scale should be of some known measure. It would have been totally unnecessary to have mentioned this condition, had it not been to prevent you from being imposed upon by venders of imperfect instruments. Some of these instruments have no determinate scale affixed to them; and those which have a scale, have one that is in general ill-graduated and erroneously placed, so that no comparative observations can be made with them; and often, indeed, no observation at all; as, from the small bore of the tube, they act as a thermometer, as well as a barometer. I have already observed, that by enlarging the scale, error is multiplied, and uncertainty produced.

3d. Condition. That the smallest changes in the height of the column of mercury may be discerned.

To measure the smallest changes, a nonius division moves with the index, by which each inch is subdivided into 100 parts, and the height of the mercury is accurately obtained without any danger from parallax, by the peculiar construction of the index.

OF THE NONIUS.

The scale of inches is affixed to the right side of the tube, the zero or beginning of the scale being at the surface of the mercury in the cistern, the index and its nonius plate slide up and down in a groove, which is parallel to the line of inches, that the index may be set at any time to the upper surface of a column of mercury.

Each inch, or line of inches, is divided into ten parts, which are again subdivided into ten, by means of the nonius scale; the whole inch being thereby divided into 100 equal parts.

TO READ OFF, OR ESTIMATE THE DIVISIONS OF THE NONIUS SCALE.

1. If that edge of the nonius scale, which is in a line with the index, coincides exactly with any division on the line of inches, that division expresses the height of the index from the surface of the mercury in the cistern in inches and tenths of inches. But, 2dly, If the foregoing edge does not coincide with any division, you must look for that division of the nonius, which coincides with a division in the line of inches, and the number on the nonius shews how many tenth parts of the ten hundredth part the index or edge has passed the last decimal division. Thus for example, suppose the edge of the nonius was to point somewhere between 29 inches 8 tenths, and 29 inches 9 tenths; then if by looking at the nonius, you observe the coincidence at 5, it shews the altitude to be 29 inches 8 tenths, and 5 parts of another tenth, or 29.85.

OF THE COMMON PORTABLE BAROMETER.

This instrument, when made with care, will answer for general and domestic observation, but is not sufficiently accurate for philosophical purposes. It consists of a tube of a proper length accurately filled with mercury; the lower end of the tube is glued to a wooden reservoir, the bottom of which is formed of leather; into this reservoir the superfluous mercury descends, and the air, by pressing upon the flexible leather at the bottom of the reservoir, keeps the mercury suspended at its proper height. This reservoir is concealed from the eye by a neat mahogany cover or box. This tube and reservoir are placed in a frame, on the upper part of which is a silvered brass plate; on the right hand side of this plate is a scale of inches, reckoned from the surface of the mercury in the cistern; each inch is divided into ten parts. Close to the line of inches there is a slit or groove for conveniently sliding the nonius scale and index up and down. The upper edge of the index and nonius scale are in a line. It is the upper edge of the index that is to be set to the upper surface of the mercury. On the left hand side of the plate the words FAIR, CHANGEABLE, RAIN, are engraved. At the bottom of the frame there is a screw passing through the mahogany box which covers the reservoir: a flat round plate is placed upon the end of the screw within the box; this end is designed to press upon the leather bag, and force the mercury up to the top of the tube, and thus prevent it from shaking, or violently striking against the top of the tube when transported from one place to another.

TO USE THE PORTABLE BAROMETER.

1. Suspend it against a wall or wainscot, so that the tube may be perpendicular to the horizon.

2. Unscrew the screw at the bottom of the frame as low as it will go, and the mercury will fall to its proper height, and be obedient to the changes in the weight of the air.

3. Set the upper edge of the index so as to coincide with the surface of the mercury in the tube, and the nonius scale will point out the height of the column.

4. Before every observation, strike the frame gently with the knuckles to disengage the quicksilver from the tube,

5. If the barometer is to be moved from one place to another, turn the screw till the mercury is pressed by it against the top of the tube.

DEFECTS OF THE COMMON PORTABLE BAROMETER.

It is necessary here just to mention some of the defects of this kind of barometer, in order to render the advantages of the better kind more conspicuous.

1. It cannot be so adjusted, as to be sure that the divisions on the scale are at that height from the mercury in the cistern, which is expressed by the numbers affixed to them. As when the mercury falls in the tube, it rises in the reservoir; and when it rises in the tube, it falls in the reservoir; its distance is perpetually varying from the divisions of the scale.

2. The tension of the leather forms a considerable resistance to the pressure of the atmosphere.

OF THE BEST PORTABLE BAROMETER.

This barometer, like the preceding, consists of a glass tube properly filled with mercury, having the lower end fixed to a wooden cistern with a leather bottom, and this tube and cistern placed in a mahogany frame.

On the upper part of the frame a brass plate is placed; on the right hand side of the tube a scale of inches is graduated on the plate, the beginning of the scale being at the surface of the mercury in the cistern: each inch is divided into ten parts, which are again subdivided into tenths by the nonius scale.

The nonius plate carries two indexes exactly similar to each other, one placed before the tube, the other behind it. The indexes may be raised or depressed by turning the key, which fits into a small hole in the frame, directly under the groove of the nonius plate.

On the left hand of the tube a small thermometer is placed, with *Fahrenheit*'s scale; there is an index to the thermometer, which may be set by the same key as the barometer, only putting it into the small hole under the thermometer, and turning it round till the index points to the mercury in the thermometer. A scale for correcting the expansion of the mercury in the barometer is often graduated close to the scale of the thermometer.

The upper part of the barometer is covered with a glass plate, to prevent the silvering of the plate from being injured by dirt, or being corroded by the action of the air.

OF THE LOWER PART OF THE BAROMETER.

The lower end of the tube is immersed in the cistern which contains the mercury; the cistern is covered with a mahogany box; at the bottom of the frame is a screw, to raise or lower the surface of the mercury; at the top of the cistern is a hole, which is fitted with an ivory screw, to be placed there occasionally for the conveniency of transporting the instrument safely from one place to another.

The gage consists of a small stem of ivory, arising from a float of the same substance; a circular division is cut round this stem; the stem passes through a short cylinder of ivory, which is cut open in front; on this front two small divisions are cut: at the bottom of this cylinder is a male screw, to fit the female screw of the cistern; the upper part of the gage is protected by a tube of glass perforated at top.

TO USE THIS BAROMETER.

1. The barometer being fixed in a perpendicular position, unscrew the screw at bottom as far as it will go without forcing it.

2. Take out the ivory screw at the top of the cistern, and place it between the scroles on the upper part of the frame.

3. Screw the gage into the place from whence the ivory screw was taken.

4. Screw up that screw which is at the bottom of the frame, until the line on the float exactly coincides with the two lines on the front of the ivory cylinder.

5. Strike the barometer gently with the knuckles, and then so set the lower edge of the front index to the convex surface of the mercury, that it may be at the same time in a line with the edge of the index behind the tube; and the nonius will then give the true height of the mercurial column, from the surface of the mercury in the cistern.

6. The preceding rule for setting the gage must be complied with previous to every observation.

7. If the barometer is to be transported from one place to another, the gage must be removed, and the solid ivory screw inserted in its place; after which, the mercury in the tube may be forced gently up to the top thereof, by the screw at the bottom of the frame.

OF THE SCALE OF CORRECTION.

This scale is placed close to that of the thermometer; but on the right-hand side, the zero, or 0 degree of this scale, corresponds to the 55th degree of the thermometer.

1. If the barometer is at 30 inches, and the thermometer at 55 degrees, no correction is necessary.

2. But if the thermometer be under 55, and the barometer at 30 inches, you must add to the height of the barometer as many of the 100ths of inches as are on the scale of correction opposite to the degree of the thermometer.

3. If the thermometer be above 55, and the barometer at 30 inches, you must subtract as many 100ths as are indicated by the given degree of the thermometer on the scale of correction.

4. The scale applied to the thermometer answers for the general range of meteorological observations; but if the height of the barometer be very far distant from 30 inches, it will be necessary to make use of the rule of three, in order to obtain the true correction: for instance, let the barometer be at 26 inches, which we call P, c the correction indicated by the thermometer, x the true correction: then as $30 : P :: c : x$; or $\frac{Pc}{30}=x$, which is to be added to the height of the barometer whenever the thermometer is under 55 degrees, but to be subtracted when it is above 55.

OF THE THERMOMETER.

No instrument is of more importance for making discoveries in meteorology than the thermometer, as it points out the temperature or degree of heat of the air and other bodies. Heat and cold are perceptions, the ideas of which we acquire by our senses. Our sensations are, however, inadequate measures of heat and cold, for they depend not only on the substance which excite them, but on the actual state of our bodies at that time: we cannot, therefore conclude the exact identity or similarity of the cause, from the sameness of the sensations, unless we can be assured that our bodies are in the same state; if they be not, the same objects will produce very different sensations. Thus, if the hand be plunged into lukewarm water, this water will appear cold, if the hand be warm; but, if the hand be cold, the water will appear to be warm; though in both cases it possesses the same temperature.

Our senses are, therefore, both imperfect and deceitful measures of heat; and we cannot ascertain, by their means only, the state of the surrounding bodies, with respect to heat and cold. This occasioned philosophers to seek for some method, by which they might determine the temperature of bodies with more certainty. This they found in the property of fire to dilate and expand all bodies, whether solid or fluid; and of cold to contract or condense them. This expansion and contraction is considered as a measure infinitely more certain of the degrees of heat and cold than the senses.

It would appear from this expansion, that fire, when it is agitated by that motion which we call heat, always acted as if it wanted more room; and this in such a wonderful manner, as if every particle of the space in which it exists were a radiant point or center, from whence it spreads forcibly outwards in every direction; and, consequently, when fire thus acting is admitted into the pores of bodies, their parts must be stretched out, and their dimensions every way increased, according to the degree of fire by which they are acted on. Some idea of the force of this expansion may be gained, by considering how vast a weight may be suspended from a bar of iron or brass in a vertical position, without separating the parts of the metal, or overcoming the force with which they cohere. Now, this fire easily executes, so far relaxing the texture of brass and iron, that their parts will fall asunder with nothing but the force of gravity.

Thermometers are instruments which measure the degree of heat by the expansion of bodies. Fluids are those generally used, because they are dilated more readily than solids; and quicksilver is preferred to other fluids, because its expansibility is not affected by the different circumstances in which it is placed; it does not soil the tube like many other fluids, and at the same time affords an extensive scale of divisions.

A thermometer is a tube of glass, the end of which is blown into a ball or cylinder; the ball and part of the tube is filled with mercury. The fluid in the ball dilates by the heat, and contracts by the cold, which occasions the fluid in the tube to rise and fall; and the smaller the bore of the tube is in proportion to the ball, the more visible will be the rise of the fluid by a small expansion. We may, therefore, consider this instrument as a convenient measure of the changes of heat and cold, which is shewn by the scale to which the tube is affixed.

But it is not sufficient to have found a measure of heat; it must be universal, always speaking the same language, and awaking the same ideas in the mind, in all places, and at all times.

To this end it is necessary, 1. That this measure should begin from a known and determinate point. 2. That another point, equally certain as the first, but at some distance from it, be fixed upon. And, 3. That the space between them be divided into a certain number of parts, which in all instruments will have a constant proportion.

It has been fully proved, that the temperature of freezing water, or melting ice, is constantly the same in all places, and at all times. The same may be said of boiling water, under a given pressure of the atmosphere. If, therefore, the ball of a thermometer be plunged into melting ice, and afterwards into boiling water, and left in each till it acquires their temperature, and marks are made at the respective heights at which the mercury stands in each, two fixed points will be obtained. To be more particular:

When ice is at the melting temperature, whatever be the heat you apply to it, it does not become hotter; a thermometer in the middle of the mass continually stands at the thawing point as long as any of the ice remains about it, so that the same cause, which in other circumstances would produce heat, here only produces liquifaction. Hence it is, that melting ice, or freezing water, is so well adapted for giving one of the fixed points of a thermometer. The quantity of fire absorbed by ice in melting, is such as would increase the temperature of the water about 140 degrees: conversely, water may be cooled 18 degrees below the freezing point, without freezing: congelation cannot take place till a certain portion of the combined or latent fire is disengaged; when any part does congeal, the fire let loose, raises the thermometer to the freezing point, and it continues there till the water is frozen; after which, as the water in the first case, so the ice in the latter, obeys the external temperature.

Continual accession of fire arrives at water when boiling, without increasing the heat thereof; for ebullition, under any given pressure, cannot take place, till the vapour produced in the liquid has obtained a degree of expansive force sufficient to raise the liquor into bubbles; under that pressure, and so long as the vapour retains this heat, it must continue capable of resisting the same pressure; as the heat abates, a decomposition takes place, which occasions the opake steam over boiling water.

These principles explain the fixity of the boiling point, for vapours cannot be formed within the mass, unless they have sufficient expansive force to displace or raise it into bubbles: they cannot acquire this force till the heat is arrived at a certain point, and as soon as they have acquired it, they escape in virtue of that expansion: further accession of fire passes off in the same manner, and only accelerates the evaporation.

Though boiling water under the same pressure has always the same heat, it may be made, before it does boil, to receive a greater heat than it can retain when it does boil. In a vessel with a very narrow orifice, filled with water, well purged of air, though the water sustains no other pressure than that of the atmosphere, yet its particles meet with so much resistance to their separation, that M. *de Luc* found it would receive, without boiling, a heat of 22 degrees above the boiling point; as soon as vapours could form themselves, their expansive force was so great, that they pushed a large quantity of water out of the vessel, in the way of explosion, but the remainder was immediately reduced to boiling heat.

The vapours of boiling water arise from within the mass, but water may yield from its surface vapours of an equal expansive force, provided they are confined in a place of equal temperature with themselves. Thus, if water be introduced above the mercury in a barometer, the vapours it produces in a temperate warmth will press down the mercury nearly half an inch. In the heat of boiling water, they will depress it to the level of the mercury in the bason; being then become equivalent to the pressure of the atmosphere in a greater heat, they will depress it below the level, and escape at the bottom of the tube, the water giving no signs of ebullition to the last.

In making thermometers, care should be taken that the tubes used for that purpose be very clean, and very dry; the next thing is to examine whether the bore of the tube is equal and cylindrical throughout; this is easily performed, by immerging one end of the tube in mercury and taking it out, previously stopping the other end with the finger; by this means a small portion of the mercury will enter the tube, more or less in proportion to the depth the tube is immerged; measure the length of this portion of mercury, and then slide it backwards and forwards in the tube. If the length thereof is the same in all parts, the tube is a regular cylinder; but if otherwise, the diameter varies, and the tube cannot be used to form a good thermometer, unless the divisions on the scale are proportioned to the different lengths of this mercurial cylinder.

The tube being chosen, the bulb is to be blown; if the tube was very regular, you may now begin to fill it; if not you must find the proportions of the inequalities to adapt the divisions thereto; to this end tie a paper funnel over the end of the tube, and pour a small quantity of mercury therein; then hold the bulb over the flame of a candle or lamp, and let some of the air pass out of the bulb through the mercury; take it now from the lamp, and as the ball cools the mercury will begin to enter the tube; admit about half an inch, take the exact measure thereof, measure the length of this portion in different parts of the tube, and you will thereby obtain data for proportioning the divisions to its inequalities.

If you have reason to suspect that there is moisture in your tube, it would be proper before the preceding operation to clean it; this may be done by laying the tube on a plate of iron, or over a chaffing-dish in which there is only a small fire mixed with cinders; it should be continued there till it is so hot that you must use a glove or a small pair of pincers to hold it, taking care not to warm the bulb. This process dilates the included air, consumes small particles of dirt imperceptible to the eye, and evaporates moisture. While things are in this state, suddenly heat the bulb, and the air being thereby dilated, drives before it all these impurities, and leaves the tube as clean as you can desire.

To fill the bulb and tube, tie on a paper funnel as before, and put somewhat more mercury therein than you think will fill the thermometer; hold the bulb over the flame of a lamp or a small candle newly snuffed, this will expand and force part of the air from the bulb; when you think a sufficient quantity is expanded, withdraw the tube from the candle; in proportion as the bulb cools, the remaining air will be condensed, and the space it occupies will be occupied by the mercury; by thus alternately cooling and heating the bulb, it is at last completely filled.

When the bulb is nearly filled, you must boil the mercury therein, by applying it over the flame of a lamp, or that of a snuffed candle. The air included in the mercury, and that which lines the tube, dilates itself, is collected in small bubbles, and expelled by the first ebullition; when the mercury boils violently, a great part of the contents will rush up the tube into the paper reservoir. Remove the bulb from the flame, and repeat the operation, till the diminished noise and agitation shews that it is deprived of its air and moisture.

After the boiling is completed and the tube cool, plunge it in melting ice or snow, which gives the temperature of 32°. Take off the funnel, and hold the bulb in the hand, and afterwards in the mouth; the heat thereof will cause some of the mercury to drop out of the tube; cool it again to 32°, and mark where the mercury stands. The distance between this mark and the top of the tube measures the interval between freezing and blood heat, or 32 and 95, that is 63°, and will consequently point out whether the degrees will be large or small, and what extent your scale is capable of.*

When the number of degrees to which the length of the tube will extend is thus known, you may settle whereabouts you will have the freezing point, which may be nearer or further from the bulb, according as your instrument is designed to measure great or small degrees of heat or cold. Now prepare the upper part of the tube for sealing, by drawing it out to a fine capillary tube; then heat the bulb in the candle till a few particles of mercury have fallen off the top of the tube, and afterwards try if the freezing point is sufficiently near the bulb; if it be not, you must repeat the operation, being careful however not to throw out too much mercury at a time. Have two candles now ready, one to heat the ball, the other to close the tube. The blow pipe being in readiness, the upper part of the tube near the flame of one candle, and the bulb near the flame of the other, the mercury will rise, and at last begin to form a globule at the point of the capillary tube; at this instant the bulb must be withdrawn from the flame of the lower candle, and the flame of upper one be directed by the blow-pipe upon the point of the tube. This will be immediately ignited, and will close by the melting of its parts before the mercury has perceptibly subsided. When the mercury has fallen, the sealing may be rendered more secure by fusing the whole point of the tube till it becomes sound.

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* *Nicholson*'s First Principles of Chemistry, p. 26, 27, 28.

To settle the freezing point, you have only to immerge the thermometer so deep in melting snow or ice, that the mercury may be scarcely visible above the surface, and then carefully mark the place at which it stands. For the boiling point, the Royal Society advise a vessel to be provided somewhat longer than the thermometer, with a cover and two holes therein; one about an inch in diameter for the steam to escape, the other smaller to hold the thermometer tube. When this is used, the thermometer must be fastened in the cover, so that the estimated place of the boiling point may be just above the hole; water then must be put into the vessel, but so as not to touch the bulb of the thermometer when the cover is placed on. The cover being put on, and a thin plate of metal laid on the steam hole, you are to make the water boil by heat applied to the bottom only; the thermometer will thus be surrounded by steam which will raise its temperature to the boiling point, and this must be carefully marked on the tube.

Fahrenheit's scale is that which is used in England: the freezing point is called 32, the boiling water point 212; so that there are 180 degrees or divisions between them, which may be extended upwards and downwards, as far as is necessary.

Foreigners generally use *Reaumur*'s, or rather *de Luc*'s scale, where the freezing point is marked 0, and the boiling water point 80.

Two thermometers are necessary for accurate observation; one to be suspended within doors, near the barometer; the other out of doors. That without doors should be placed at the north side of the house, or where it will be sheltered from the rays of the sun.

I have already shewn you,* that the increments of expansion in a mercurial thermometer are nearly as the increments of heat; or in other words, that the dilatations and contractions of the fluid are nearly proportional to the quantities of fire, which are communicated to, or separated from the same homogeneous body as long as they remain in the same state. Thus the quantity of fire required to raise a body four degrees in temperature by the mercurial thermometer, is nearly double what is required to raise it two degrees, and four times what is necessary to raise it one. This is proved by putting a thermometer first in cold water, and then into water heated to any degree, noting the altitudes; then putting equal quantities of these two waters together, which will give a mean heat, and the mercury in the thermometer will stand at the mean altitude between the two before observed; this is found to be true, whatever be the temperature of the two parts of water.

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* Vol. i. p. 322, 323, see also p. 474 to 480.

Though in the sense here explained the thermometer is an accurate measure of heat, yet I have also shewn you, that it can only indicate the proportions of that action of fire by which bodies are expanded, but is by no means a measure of the whole quantity of fire disengaged, displaced, or absorbed; properly speaking, it is therefore only a scale of expansion indicating certain translations and transfusions of the igneous fluid.

It may be proper to observe to you, that glass is dilated and contracted by heat and cold together with the fluid, and consequently the apparent variations in the dimensions of the fluid are the difference between the real cotemporary expansions, or sum of the cotemporary contractions of the glass and the fluid. The changes arising from these causes are too inconsiderable to be worthy of notice in the general use of this instrument; the change of dimension in the glass is prior to that in the fluid; hence the fluid is found to sink before its rise upon an increase of temperature; and if the bulb be large, some time may elapse before the fluid acquires the same temperature with the glass. The pressure of the atmosphere on the outside of the bulb not being counteracted by the air within, will affect its magnitude, diminishing it as the pressure is increased. The variation on the scale occasioned by this cause is, like the preceding one, very small, being never above one-tenth of a degree.

OF THE RAIN-GAGE.

It is necessary towards forming a systematic idea of the weather and its various changes, to measure the quantity of rain which falls upon the earth; and this is done by what is called a *rain-gage.*

The rain-gage is a very simple instrument, consisting of a square tin funnel of twelve inches diameter, communicating with a tube or cylinder of tin, into which the rain is conveyed by the funnel. The depth of the water is measured by a rule fixed to a float; this rule passes through the center of the funnel. The divisions on the rule shew the number of cubic inches of water that have fallen on a given time on a surface of one square foot.

To use the rain-gage, so much water should be first poured in as will raise the float, so that the zero on the rule may exactly coincide with the aperture of the funnel. The funnel is so contrived, as to prevent the water from evaporating.

This gage should be fixed down firmly in a place where, whatever winds blow, the fall of the rain may not be intercepted by the house, or any other impediment.

OF THE HYGROMETER.

The *hygrometer* is an instrument intended to discover the moisture contained in the atmosphere.

As the substances that are affected by moisture are very numerous, so are also the contrivances that have been executed to indicate the degrees of moisture, and render sensible the smallest variations in the substances influenced thereby. Thus, wood expands by moisture and contracts by dryness; on the contrary, cord, catgut, &c. contract by moisture and lengthen by dryness; consequently, the contraction and expansion of these substances indicate different states of the air with respect to moisture. The twisted beard of a wild oat, with a small index fixed to it, moveable against a scale, makes a very good hygrometer; for the twisting, being affected by the variations of moisture, moves the index.

Mr. *de Luc*, who has laboured more on this subject, and with more success than any other man, after making an immense number of experiments to find out a substance, whose expansion increases most, nearly in proportion to the quantity of moisture imbibed, found that whalebone and box, cut across their fibres, increased very nearly in proportion to the quantity of moisture, and more so than any other substance which he tried. He however preferred the whalebone; 1st. On account of its steadiness, in always coming to the same point at extreme moisture; 2dly, On account of its greater expansion, increasing in length above one-eighth of its length, from extreme dryness to extreme moisture; lastly, Because it is more easily made thin and narrow.

As the whole atmospheric economy, as far at least as relates to the weather, depends upon, or is connected with the state of vapour it contains, it is rather surprizing, that we find so few hygrometrical observations among the many meteorological diaries that have been published. From time immemorial, the effects of moisture have been considered as prognostic of the weather, as is evident by the confidence the housewife places in her salt-box, the carter in his whip leather thong, and the sailor in his shrouds. But whether the hygrometer be a prognostic or not of the weather, it is certainly of the utmost importance to the natural philosopher, and would probably prove a valuable oracle to the farmer, which is fully evinced by the following observation of Mr. *Marshall*, in his minutes of agriculture. "Yesterday morning, says he, while the hygrometer stood at two degrees moist, the peas were by no means fit for carrying; the balm was green, and the peas soft. About ten o'clock the hygrometer fell to one degree dry; before one, the peas were in good order; I went into the field, merely on the word of the hygrometer, and found the peas fit to be carried." It is plain therefore, that on a scattered farm, in hay-time and harvest, an hygrometer must be peculiarly useful.

Before I proceed to take further notice of hygrometers, it will be necessary to remind you of the principles I have already laid down concerning evaporation and vapour; for, unless these are properly attended to, you will never be able to attain any fixed and certain notions of meteorology. Atmospherical fluids are divisible into two classes, vapours and aeriform, the distinctive characters of which are these: vapours are decomposed by pressure, but aeriform fluids bear the strongest compression without decomposition: vapours are decomposed in vessels hermetically sealed by the spontaneous escape of fire; but aeriform fluids can only be decomposed by some substance, to which their gravitating matter has more affinity than to the fluid which maintains them in an aeriform state. In vapours the proportions of the component parts are very variable, according to the subsisting circumstances; but aeriform fluids, when once formed, continue in the same state, and can only be changed by chemical causes: the difference arises from the weakness of the union of water in vapour with fire, so that it can separate itself therefrom by the mutual tendency of its own particles, when they are brought within a certain distance one of the other, and because fire can so easily quit them, to restore certain equilibria with respect to itself.

By watery vapour, I do not here mean visible opake steam or vapour, because that is vapour in a state of decomposition; I mean the invisible and transparent exhalations, which constitute a peculiar and distinct fluid, expansible and compressible, and so, far from possessing the mechanical properties of aeriform fluids, and exercising these properties whether mixed with them or alone.

The specific gravity of these vapours is above one half less than that of common air; that is, when they exercise a certain expansive force, whether alone or mixed with air, their mass is above one half less than a like volume of air, which would exercise the same expansive force.

In the course of our Lectures on Fire, I shewed you, that vapour consists of particles of fire, united with those of water, and that there was no foundation for the hypothesis which considered it as a chemical solution of water by air. This is, however, an hypothesis that has been adopted by so many writers, though contrary to every circumstance duly examined, and of such consequence in meteorology, that I shall again make a few remarks thereon. I shall first notice the phenomena of air contained in water, and shew you, that these have no relation to the common notions of solution. If water be placed in a receiver, and a vacuum made, a number of air-bubbles are formed in the midst of the water, which increase in size, and then escape. Now, there is no principle in the theory of dissolution which can explain, why a menstruum, because it is less pressed, should let go the substance that it had dissolved; whereas it should hold it stronger if the menstruum is thereby dilated. When the water ceases to produce air by this operation, if you agitate it strongly, more air is disengaged; this also is contrary to the theory of dissolution, for this is promoted by the agitation of the menstruum. When both these methods cease to be efficacious, more air may be disengaged by heat; here the hypothesis is contradicted at its very foundation; the sole plausibility on which it rested was derived from the idea, that the air could contain more water when its heat was greatest, which of course must also take place with respect to air contained in water, to which you see this fact is diametrically opposed. I have shewn you in the Lecture on Fire, that the phenomena of aqueous vapour are the same in vacuo as in open air, that it may be produced in vacuo without any concurrence of the air. The density of the vapour is the same every where at any temperature, provided the particles thereof keep at a certain distance from each other. This density in every space, and at every temperature, is determined by a certain minimum distance among the particles of the vapour. It is sufficient for their conservation as vapour, either in vacuo or in air, that they are not forced to approach within this distance. The product of evaporation is always of this nature, namely, an expansible fluid, which either alone or in air affects the manometer by pressure, and the hygrometer by moisture, without any difference arising from the presence or absence of air. I may again, therefore, repeat after M. *de Luc*, that every phenomenon proves, that the hypothesis of the solution of water by air is vague, without any solid foundation, unnecessary for the explanation of evaporation, while it involves every branch of philosophy in obscurity.*

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* See M. *de Luc*'s Letters, dans le Journal de Physique, his Idees sur la Meteorologie.

See also further proofs of the errors of the chemical idea of water being solved by air in Vol. ii. Lecture xiv. p. 76 and 77.

Evaporation is a dissolution of water by fire. A most decisive reason in support of this opinion is, that every liquid cools when it evaporates; the portion of the liquid that disappears, being carried away by a quantity of fire proceeding from the liquid itself. Mr. *Watt* has shewn, that in the common evaporation of water in open air, the quantity of heat lost by the mass, bears to the quantity of water carried away, a proportion still greater than that which is found in the steam produced by boiling water.

As vapour consists of fire and water united, and forming a new compound, the specific properties of each of the component parts are in certain respects suppressed, as in other chemical operations, the water loses its faculty of moistening, and the fire that of producing heat; hence the loss of heat in the evaporation of liquids, and the augmentation of heat in the decomposition of vapour. The particles both of fire and water still, however, retain the faculty of maintaining their respective equilibrium between the medium and surrounding bodies. Thus the particles of water still retain the tendency of uniting together, and this union takes place whenever they are so near each other, that this tendency can surmount the effort of the fire which keeps them disseminated.

Of course, the less the quantity of free fire, or the cause of heat, in a given space, the greater is the distance at which the particles of water can exert their faculty of uniting together, and of abandoning their latent fire. The precipitation of water or final union, therefore, takes place when the density of vapour has exceeded certain limits, which limits depend on the temperature; for the greater the quantity of free fire in any given space, the nearer the particles of vapour may approach each other without being decomposed, that is, without the watery particles, in consequence of their natural tendency, re-uniting together, and quitting the fire with which they were associated.

Thus there is necessarily a minimum of distance of the aqueous particles, beyond which the vapour cannot be compressed without being decomposed; and this is different in different degrees of heat, but constant in the same. When vapours are mixed with air, they can sustain a much greater pressure than they can by themselves, because the air supports the pressure, and prevents the particles from being forced within their minimum distance; and it is thus that vapours subsist in the atmosphere without being decomposed by its pressure.

Vapours are decomposed not only by the mutual approach of the particles, but also in virtue of the affinity of water to those substances that are called *hygroscopic*, of which fire may be reckoned one. The principal law of this affinity is, that the water distributes itself to all the substances of the class that are within its reach, to every one alike, proportional to its capacity of retention. If new fire be introduced into a given space, where there is no superabundant water, it will take away some of the water from all the hygroscopic substances, and diminish their humidity. If some of the fire be taken away, the water that was united thereto will be divided among all the rest; and if any other hygroscopic substances be introduced, containing a greater or less quantity of humidity than those already there, the surplus of humidity will be divided among them. It is by fire that this distribution is effected; the particles of this element being always in motion, take up the water from one that has more than its share, and give it out to another that has less. Thus hygroscopic substances have their humidity always proportional to the places they are in.

Hygroscopic substances are of three distinct classes: 1. Those that seize on the water of vapour by a chemical affinity with that liquid; among these are acids, salts, and calces. 2 Those that imbibe the water, by the tendency it has to propagate itself in capillary pores, but from their nature receive no sensible increase of bulk by its introduction; such are porous stones. 3. Those that, imbibing a certain quantity of water, are thereby expanded; and these are most of the solids of the vegetable and animal kingdoms. M. *de Luc*, by a long series of experiments, to which I must refer you, shews, that the substances of the last class are the only ones proper for hygrometers, and that even in this class, to avoid fallacy in respect to the most important phenomena, we must use those that cease to lengthen, only when they can be penetrated with more water.

Here, however, it will be necessary to define in what sense we use the words *moisture* and *humidity*, for in the manner they are commonly used, they sometimes imply a cause, sometimes an effect; this ambiguity is not peculiar to these words, you will find many others used in philosophy as ambiguous, particularly when they have been applied to certain phenomena, the causes of which are not determined.

Moisture, in a general sense, may be considered as invisible water, producing observable phenomena.

Thus in hygroscopic bodies, the quantity of water which expands them, and increases their weight, is concealed within their pores; and in the ambient medium, that water which affects hygroscopic bodies, being there under the form of vapour, is as invisible as the air itself.

But in respect to hygrometry, where moisture is considered as having correspondent degrees in the medium, the word requires a more particular determination. Moisture may be either totally absent or absolutely extreme, both in the hygroscopic bodies and in the ambient medium; hence, both in the whole and in correspondent parts, moisture assumes in the medium the character of a cause, and in hygroscopic bodies, that of an effect. These two circumstances furnish us also with a fixed module for determining correspondent degrees.

Moisture is totally absent, first, in the medium when it contains no vapour; and then as a consequence in hygroscopic bodies, because they contain no more water that can evaporate, without a decomposition of their component parts. The case here supposed is, that when, by some adequate cause, no sensible quantity of vapour is permitted to remain in the medium, as in the lime vessel used by M. *de Luc* to obtain the point of extreme dryness.

Moisture is extreme, first, in the medium, whether air or a space free from air, when no more vapour can be introduced therein, without a part being decomposed; and then, as a consequence in hygroscopic bodies, because no more water can be admitted in their pores.

Here it is to be observed, that from the nature of the last of these maxima the quantity of water which produces it, *i. e.* extreme moisture, in a given body is fixed, because it is determined by the actual capacity of its pores; but the quantity of water which produces extreme moisture in a medium of a given extent, is as variable as the temperature.

The equilibrium, therefore, between the medium and hygroscopic bodies in different stages of moisture, which equilibrium is the object of hygrometry as a science, does not depend on certain quantities of water contained in the medium of which bodies may receive their share; it depends on different aptitudes of the vapour contained in the medium, to communicate water to those bodies; which aptitudes vary not only with the different densities of that fluid, but also in vapour of the same density according to the temperature.*

From the hygrometer we have learned, that in the phenomenon of dew, the grass often begins to be wet when the air a little above it is still in a middle state of moisture; and that extreme moisture is only certain in that air, when every solid exposed thereto is wet. It has taught us, that the maximum of evaporation in a close space is far from being identical with the maximum of moisture; this depending considerably, though with the constant existence of the other, on the temperature common to the space and the water that evaporates. It has shewn, that the case of extreme moisture existing in the open transparent air in the day, even when it rains, is extremely rare; M. *de Luc* has only found it once in this state, the temperature being 39°. Messrs. *de Saussure* and *de Luc* have proved by the hygrometer, that the air is dryer and dryer as we ascend in the atmosphere; so that in the upper attainable regions, it is constantly very dry, except in the clouds. M. *de Saussure* has shewn, that if the whole atmosphere passed from extreme dryness to extreme moisture, the quantity of water thus evaporated would not raise the barometer half an inch. Lastly, in chemical operations on the air, the greatest quantity of evaporated water that may be supposed in them at the common temperature of the atmosphere, even if they were at extreme moisture, is not so much as the one-hundredth part of their mass. The two last very important propositions have been demonstrated by M. *de Saussure*.†

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* See M. *de Luc*'s paper on Evaporation, from which the remarks on Hygrometers, &c. is an extract, Phil. Trans. for 1791, part 9.

† See M. *de Luc*'s second paper on Hygrometry, Phil. Trans.

LECTURE LII.

OF RAIN.

In a science so very difficult as that of the weather, it is not to be supposed that any thing like a certain and established theory can be laid down: our utmost knowledge in this respect goes no further as yet than the establishment of a few facts; and in reasoning upon these, we are involved every moment in questions which seem scarcely within the compass of human wisdom to resolve.

To treat it in a satisfactory manner, we ought to have an intimate acquaintance with the constitution of the atmosphere, and the nature of those powerful agents, fire, light, and electricity, by which it seems to be principally influenced; with their peculiar influences upon one another and upon the atmosphere, and this in every possible variety of circumstances. Many of the qualities of air, earth, water, and fire, have been indeed discovered and estimated; but when these come to be united by nature, they often produce a result which no artificial combinations can imitate. Every cloud that moves, and every shower that falls, serves to mortify the philosopher, and to shew him hidden qualities in air and water that he is unable to explain.

The greater part of the received notions on meteorology are vague and incorrect, not only those which relate to the nature of the causes, but those also which concern the laws of their effects. The same may be said of our notions of the elasticity of the air, of heat when applied to this fluid, of both igneous and aqueous meteors, of sudden and partial winds; they are all so many enigmas to the philosopher.

Indeed, till we were in possession of a good hygrometer, it was impossible to form any certain conclusions concerning the moisture of the air: this difficulty is removed; M. *de Luc* has by numerous experiments and observations furnished us with a comparative hygrometer, by which, together with a thermometer, the air can neither lose nor acquire moisture without our being advertised thereof.

By the use of this hygrometer we have obtained clear and certain ideas of the causes, by which water, simply evaporated in air, may be precipitated therefrom. These causes are the same with those, which in air, where the quantity of evaporated water remains the same, always produce an increase of moisture, the necessary forerunner of the precipitation of water; and these are two, *viz.* the compression of the air, or its being cooled: no other causes are indicated by experiment. Some philosophers have thought that the air, when rarefied, quitted a portion of the water which, according to them, it held in solution; but I have shewn you that this idea is erroneous, and that rarefaction occasioned dryness instead of moisture.

The great question, therefore, in the inquiry concerning the immediate cause of clouds, &c. is, What becomes of the water that rises as vapour into the atmosphere? What is the state in which it subsists there, between the time of its evaporation and the time of its falling down again in rain?

If it continues in a state of watery vapour, or such as is the immediate product of evaporation, it must possess the distinctive characters essential to that fluid. It must make the hygrometer move towards humidity in proportion as the vapour is more or less abundant in the air. On a diminution of heat, the moisture, as shewn by the hygrometer, would increase; but, on an increase of heat, the humidity would decrease. Again, on this supposition, if hygroscopic substances dryer than the air be introduced therein, they must have the same effect as an augmentation of heat: for, such are always the properties of aqueous vapour on every hypothesis of evaporation. If, therefore, water exists in the atmosphere without these properties, it is no longer vapour, it must have changed its nature. M. *de Luc* has shewn, that the water which forms rain, does not possess these properties; it must, therefore, have passed into another state.

Repeated observations have shewn, that the upper regions of the atmosphere, notwithstanding the continual ascent of vapours there, are dryer than the inferior regions; on the summits of high mountains a degree of dryness prevails unknown on the plains.

If rain be the immediate product of evaporation, it ought always to be preceded and accompanied by a diminution of heat, in that stratum of air where it originated; and this diminution, to produce its effect, should be greater in proportion as the moisture was further removed from its extreme term in this stratum; but, in a great storm on the mountain of Sixt, M. *de Luc* found that the heat had increased instead of diminished; this cause could not operate here, and it was therefore impossible that the quantity of water which was then precipitated from the air could have been contained there in the form of the immediate product of evaporation.

On every hypothesis of the formation of rain from vapour, it is heat that produces the evaporation, and a diminution of heat that occasions the return of vapour into water, and therefore rain should happen only in the night, or at the coldest time of the day; whereas experience shews, that it has no connexion with heat or cold. We have rain as often in the day time, when, according to the natural course of things, the heat of the atmosphere should be the greatest; as at night, when the heat ought to diminish; besides, the heat often diminishes in the day, without producing rain. Whatever be the degree of heat, the air can only part with so much of its water, as it is unable to retain in that degree of heat; no rain should therefore be formed, unless the air was saturated, or at extreme moisture, but this also is contrary to fact.

Thus, when M. *de Luc* and his brother were on the Sixt, though the hygrometer was $66\frac{1}{2}$ degrees from extreme humidity, thick clouds formed around them, which obliged them to think of retreating; in a little time the summit of the mountain was surrounded by them, they spread and covered the whole horizon, a premature night surprized them in a very dangerous road, and a most violent storm of wind, rain, hail, and thunder, lasted the greater part of the night; it extended over all the neighbouring mountains and plains: after the storm ceased, the rain continued with very few intermissions till the next day at noon. The hygrometer being examined in one of these intervals, only shewed $1\frac{6}{10}$ more moisture than before; and even this increase was no other than what the difference of heat was sufficient for producing; nevertheless, new clouds were formed, and the rain began again, accompanying our travellers by fits to the bottom of the mountain; when arrived there, the clouds entirely dispersed, the hygrometer was again observed in the open air, and though the earth was drenched with water, and the heat much less, the hygrometer was $1\frac{7}{10}$ dryer than it had been two days before, after a course of fine weather. Now, where was all this water, and all the ingredients of the storm, while the hygrometer shewed such a degree of dryness in the stratum where it was formed?

The reasoning of M. *de Luc* is confirmed by the phenomena of fair weather; continued evaporation from the inexhaustible source of vapour, the ocean, and from the earth after it has been soaked with rain, would, if vapour did not change its nature in the atmosphere, render it more and more humid, and bring it at last to a maximum of humidity, as it does under a glass receiver. But experience shews, that though the evaporation continues for several months together on vast extents both of seas and continents, the air does not become moister, but on the contrary, more and more dry. The diminution of heat in the night produces dew; but this symptom of humidity diminishes from day to day, and sometimes ceases altogether.

Many attribute the ordinary occurrences of rain to changes in the winds. When it rains with a south wind, it is supposed that these winds are warm, because they come from the south, and that they are more humid because the greater heats in those climates from which they proceed, ought to produce a greater degree of evaporation; and that, consequently, when this air meets with a colder part of the atmosphere, the water it contained would be precipitated. If it rains by a north wind, it is imagined, that this wind being colder than our air, produces the same effect that this did upon the south wind. There are, however, various reasons which prove, that these winds are not the immediate cause of the phenomena.

To place this hypothesis in the most favourable light, we will suppose that one stratum of air is at rest and the other in motion, and that both are saturated with the immediate product of evaporation. But the quantity of evaporated water, which constitutes saturation or a maximum of humidity in the air, varies with the temperature, augmenting or diminishing with the heat. The colder air will, therefore, contain proportionally less evaporated water than the other. When these two airs meet, the one will be cooled, which should produce a precipitation of water; but the other will at the same time be as much heated, and therefore capable of receiving the superfluous water: at first a mist may be formed, but this will not be durable; for, as it is in contact with the air that is growing warmer, it is soon dissipated.

It sometimes rains with a south wind, which seems to embrace the whole height of the atmosphere; here it has been gratuitously supposed that this air proceeded from the torrid zone, saturated with water throughout its whole height. Granting this supposition, it will not account for the phenomena of rain, I shall not consider here the difference in the seasons, which ought necessarily to influence these phenomena, which however is not perceived; for we have often durable rains with this wind in summer, when the change of climate will occasion little or no variation in its temperature. Whatever change the heat of this air undergoes, it will gradually take place on account of the vicissitudes of day and night; for, as soon as the rays of the sun cease to act upon our horizon, the heat in the air decreases in as great a degree as that in which it existed at the same hour of the day. If the air is thus cooled beyond a certain point, the excess is precipitated in dew: besides, moisture in the atmosphere is daily destroyed by some cause of which we are ignorant, and re-appears as suddenly in vast abundance in some strata, by causes of which we are equally ignorant. If you consider attentively the consequences of all these facts, you will see that there is very little probability that air, which travels night and day to come to us, and which must necessarily conform, and that successively, in all the intermediate latitudes, to the various causes that determine their mean degrees of humidity and heat, can ever occasion the phenomena attributed thereto.

The remarks I have just made on the effect supposed to be deducible from different winds, are formed from the notions we gain by observations made in plains. They are strengthened and confirmed when connected with observations made on mountains, for there these winds are found without those deceiving appearances which favour the hypothesis we are combating; they are found to convey cold there, while they are communicating heat to the plains below. Now, if the south wind derives its heat from the climate whence it proceeded, why is it not warm on the tops of mountains as well as in the plains? If it be said, that it is cold also on the tops of high mountains in the torrid zone, we reply, that if so, this in itself is a great mystery; and further, that no one can suppose that the superior air of this zone preserves its position and degree during its whole passage, and arrives in the same state at the tops of the northern mountains; and we may conclude, that though the air which proceeds from climates warmer than our's be then hotter than the air surrounding us, yet, the greatest heat we find therein does not in general proceed from this cause, but from some difference in its nature, whereby the solar rays are rendered more powerful and more capable of producing heat near the surface of the earth.

From observations that have been made on mountains, we may draw the same conclusions with respect to the humidity that generally accompanies south winds near the earth. For from these we find, that they do not produce the same effects in the higher region of the atmosphere, but accord with the usual dryness of these superior strata; they are not, therefore, in themselves the immediate causes of these differences; for, if this were the case, the higher regions would be as much affected as the lower, or they could not be considered as an assemblage of the same fluids. But in this assemblage there may be unknown fluids, on which the solar rays may in the lower regions have a different influence, arising from circumstances of which we are ignorant, perhaps from a greater or less density in the mass, or from a difference in their distances from the soil of the earth. Every circumstance seems to indicate, that chemical operations are the general cause of the phenomena, though in a manner unknown; among the agents concerned, the solar rays hold the first rank.

The necessity of the solar rays for the fructification of vegetables has been long established; Messrs. *Priestley*, *Ingenhouz*, and *Sennebier*, have proved that this operation is accompanied by great modifications in the air, modifications which are essentially altered by the presence or absence of the solar rays. By these operations we see new solids rising before us; and yet, if we are scrupulous in the connexion of causes with effects, we must confess our inability of tracing here the combinations of this first substance, which evidently puts in action every substance on our globe. We know in this instance, that some of the substances belong to the atmosphere, some to the earth, and that both are modified by the solar rays: fire also participates, but light is a constituent part of fire: water has its share, but water contains fire and light: some ingredients of air are joined thereto; but of these ingredients, those that are united depend on the quantity of light.

Thus, however, new compounds are formed, possessed of different colours, consistency, odour, flavour, and chemical properties. All these wonderful operations are produced by the medium of the solar rays from the atmosphere and from the earth: and these modifications taking place on the earth and on the waters, over the whole surface of the globe, must be considered as a class of causes which have considerable influence in meteorology.

OF THE NATURE OF CLOUDS.

From considering the causes of rain, I proceed to investigate the nature of clouds. As it is from these that rain proceeds, we must acknowledge the blessings we receive through them, though we are not able to account for their various phenomena. They are continually travelling over our globe, and by a proper distribution of moisture, rendering the spacious pastures of the wealthy fruitful, and gladdening the little spot of the cottager. "They satisfy the desolate and waste ground, and cause the bud of the tender herb to spring forth;" that the natives of the lonely desert, the herds which know no master's stalls, may nevertheless experience the care of an All-supporting Parent.

Clouds are composed of a mass of vesicles like soap-bubbles, which vesicles are easily perceived in proper situations, particularly on high mountains: these vesicles float in the air, rising or falling, till they are in equilibrium with the air, remaining suspended there as long as they preserve the same state. By the nature of the suspension of these aqueous vesicles, they do not alter the pressure exercised by the strata in which they are inclosed, neither on itself nor on the inferior strata.

When the particles of vapour, properly so called, approach within a certain distance of each other, which is determined by the actual quantity of free fire, the particles of water, of which they are composed, tend to unite, and the fire which quits them joins itself to the remaining particles of vapour. From the observation of M. *de Luc* it appears, that vesicles of liquid water may be formed, and exist when the temperature of the air is at freezing. I have already shewn you, that there is something else besides cold, necessary to the formation of ice. It is hence we see mists, fogs, and clouds, when the thermometer is under 32°. There is never, however, any great cold in fogs or in clouds, for the cause, whatever it may be, that brings vapour beyond its maximum, disseminates also heat. Aqueous vesicles never freeze without changing their state; but if the bubbles are broken when the air is at or under 32 degrees, the water thereof freezes: if this happens in the midst of clouds, snow is the consequence, whose duration, like that of rain, depends on the quantity of vesicles that are brought within a certain distance of each other; the destroyed vesicles then group themselves into flakes of snow by a crystallization, somewhat similar to what are termed by chemists *sublimations*, *i.e.* the precipitations of substances dissolved by fire. If the quantity of aqueous vesicles is too small to unite and be destroyed, by being brought near together, they may be destroyed and frozen by causes similar to those which fix sublimates to the sides of the furnace and other receivers, or which determine congelation in water sufficiently cooled. In this case a hoar frost is formed.

Clouds are always composed of bubbles, formed of liquid water, and they are generally at a temperature very little above the freezing point; the existence of these vesicles or bubbles is but of short duration, they rise and are destroyed successively, like the brilliant sparks we often perceive rising from a chafing dish, when the coals are animated by a bellows.

OF THE DURATION OF CLOUDS.

Whenever we see a mist or a fog formed by a known cause, we are always certain that the vapours, from which it proceeds, are passing rapidly beyond their maximum; and the mist ceases when no fresh vapour arrives for its support. The principal known causes of mists and fogs are either the ebullition of water in open air at all temperatures, the transpiration and respiration of animals in winter, the evaporation from hot springs in the same seasons, and the fogs, properly so called, that happen in autumn. In all these cases we know, that the vapour is produced in too great abundance for the temperature of the neighbouring air; hence a rapid destruction of a part of those which arrive in that space which is occupied by the fog. Meanwhile, the fog only occupies a certain space, which is nearly fixed as long as the circumstances remain the same; in a word, we always find fogs and mists to cease, as soon as the cause producing the vapours ceases to furnish them beyond the maximum suitable to the temperature of the air; the vesicles are formed by a rapid decomposition of superfluous vapours; as soon as this ceases, the vesicles are dissipated.

From a review of known facts you will find, that the following conclusions are well founded. 1st. That vesicles are only formed in those cases where vapours get beyond their maximum. 2. That these vesicles are concrete water, subject to evaporation like any other water, and which always evaporate when the surrounding air is not at the extreme point of humidity. 3d. It is this last mentioned circumstance which determines the extent of space occupied by a cloud or fog; for these vesicles only exist in that part, where the source of vapours, whatever it may be, having produced extreme humidity, disseminates superfluous vapour; so that beyond this space the vesicles evaporate. 4thly and lastly. This evaporation is prevented in whole or in part, either by obstacles that oppose the expansion of the mist or fog, or because the source of vapours furnishes them so rapidly, that the vesicles approach near enough to unite even in the midst of the fog, which occasions them to unite, and the result is a distillation of water. From hence we may conclude, that when a cloud is formed in air, whatever be the cause, it can only subsist there while aqueous vapours continue to be produced in the same place. Thus, the extent occupied by a cloud is an indication of the cause which produces vapours, or of its intensity in some part of this space: extreme humidity exists but very little beyond the extent of the cloud, and, as soon as the cause which furnishes the vapour ceases, the cloud dissipates.

We have been accustomed to see clouds from our earliest infancy; they therefore neither excite attention, nor awaken admiration; and yet, of all the objects which surround us, there is none more truly wonderful, or more worthy of attention. Those also, who have but little studied the laws of hygrology, are very little astonished at these appearances, because they either suffer themselves to be amused by words, or rest satisfied with a few seducing glimpses: those who have considered the laws of hygrology, and weighed all the circumstances, find they are only carried to the boundaries of known causes; but they also know how to stop and wait there, till fresh light enables them to proceed further.

The traveller who has frequented high mountains knows, that clouds are a species of fog or mist, much resembling those we perceive on plains; he has also remarked, that where clouds are scattered in the air, the strata where they are met with are not at extreme humidity. Among other instances, M. *de Luc* mentions one where he saw his own shadow, and that of the rock on which he was situated, projected on a cloud beneath him, in a stratum where there were many other similar clouds extending to a considerable distance. The air was very serene, and there was not the least symptom of extreme humidity. How are such clouds preserved? Whence do they increase to the eye? Why, as they are continually evaporating, are they not immediately dissipated?

The evaporation of clouds, even while they are increasing in size, is a circumstance of which you may easily be satisfied, by considering attentively the broken edge of a cloud, which has an azure ground behind it. These edges present to the imagination a thousand grotesque forms, which, by their striking changes, will assist you in your researches. Often you may perceive the part you are looking at dissipated in the place where it was first observed; often it stretches itself out, the cloud remaining stationary, and vanishes while it is thus extending itself. Sometimes, while one festoon vanishes others are formed, by which the cloud is enlarged; at other times it diminishes, the festoons successively evaporating, till the whole disappears. It is impossible to consider these various metamorphoses of the same cloud, without supposing that there is in the air a source of vapours, which are produced in the place where the cloud is formed, and that it is by the continued production of fresh vapour that the cloud subsists and increases, though continually evaporating. When they wholly disappear, it is because the evaporation is not repaired by the formation of fresh vapour. These phenomena are independent of heat and cold, for clouds are sometimes formed suddenly in the midst of a hot day, and after they have poured down their water, all is clear again. Sometimes they evaporate after sun-set, gradually vanishing in the calmest weather, without change of place. The appearances, on the whole, are such as would be produced by a large mass of water in violent ebullition, suspended invisibly in the atmosphere; and the similarity in the effect naturally points out an analogy in the cause, that is, a source of vapour in the atmosphere.

When it rains, the source which furnishes vapours produces them in such abundance, that the vesicles which are formed are driven against each other even in the bosom of the cloud; and not having time either to disperse or evaporate, they are united; and the water falling to the lowest part, as in soap-bubbles, they are soon burst, and fall as rain. It is to these surcharged vesicles we must attribute the pendent fringes which are sometimes seen under the clouds towards the horizon. Experience has shewn, that it rains under those clouds; not that these fringes are rain itself, but the vesicles which fall by the augmentation of their weight. As drops of rain are formed their vesicles are destroyed.

Lasting rains proceed from strata of clouds which cover the whole heavens; and it is these that have the greatest connexion with the fall of the mercury in the barometer. The source of vapours comprehending a stratum of considerable extent, the barometer, after it has announced these rains, generally rises, and continues to rise, as long as they last. This is a fact observed, but to us inexplicable. It is no doubt connected in some way with the primitive cause of rain, but with that cause we are unacquainted. The relation of rain with the barometer is a subject as obscure as the cause of rain itself.

In the midst sometimes of the finest days, and while ordinary symptoms indicate that the air is dry, and this as well in the vallies as on the mountains, bright and heavy clouds appear on azure ground, announcing sudden rains. Sometimes these clouds increase enormously and descend; other clouds form about, and unite to them; the air is darkened, as if a curtain was drawn between heaven and earth. From the tops of high mountains, these clouds may be often seen to accumulate rapidly over the plains; while from these the azure ground of the heavens disappears; the wind often rises, and blows from different quarters in a kind of whirlwind; and lastly it pours with rain. As soon as the rain ceases, the curtain is withdrawn, and the calm is restored, the sun re-appears, and no other vestiges remain of this grand phenomenon but the water that is on the ground.

When the air is disposed to produce this phenomenon, you will often see the clouds rising from the horizon; sometimes from the side where the wind proceeds, sometimes from other quarters. Often these heavy showers are partial: sometimes they recommence at intervals, accompanied with heavy squalls. Sometimes these heavy intermitting showers are a prelude of more lasting rains; in which case the clouds unite, and the wind goes down, and you have one or more successive days of rain.

OF HAIL.

Sudden storms, accompanied with hail and thunder, are among the number of phenomena which shew how ignorant we are of the causes of those that we observe in the atmosphere. *Hail* is a sign of a great degree of cold; but what is the immediate cause thereof? Whence a substance, that must require so intense a cold for its formation, in seasons so warm as those in which hail is chiefly formed? It is supposed in general, that hailstones are drops of rain, which, falling through a colder region of air, are congealed in their passage into a-rarefied sort of ice. Dr. *Halley* gives an account of hailstones that weighed five ounces each, and says, it is very extraordinary that such sort of vapours should continue undispersed so long a tract as sixty miles together; and in all the way of it passage occasion so extraordinary a coagulation and congelation in the watery clouds, as to increase the hailstones to so vast a bulk in so short a space as that of their fall.

OF THUNDER.

All the phenomena of stormy clouds are obscure, and I am afraid there is very little probability of explaining them independent of each other. Those that are satisfied with conjectures may find enough at their service; but he who conducts himself by the "scale and chart of truth," will find little to depend upon. It is thus with thunder and lightning: we can neither account for the immense quantities of electricity discharged by the one, nor the rumbling noise of the other.

Mr. *Volta* supposed, that water, by being changed into vapour, acquired a greater capacity for the electric fluid, and that thus electricity was continually conveyed to the atmosphere by evaporation; and this he deduced from an experiment, in which water being evaporated from a body, left that body negatively electrified. This, however, is by no means satisfactory; for, not to insist on the fallacy of the terms *positive* and *negative*, as both electricities may be produced by evaporation, if the electric fluid passed from the earth to the atmosphere by evaporation, and its return was occasioned by the reduction of vapour into water, there would always be more or less lightning when there was violent and sudden rain, for in this case it would be rapidly disengaged; but there is much oftener violent and sudden rain without than with lightning. In this case lightning also should always be preceded by rain, whereas there is often lightning among the clouds without any rain. Further, if we are unable to explain rain by the vapours which existed in the air before the formation of the clouds, the source of electricity existing in the clouds ought not to be sought for in vapour. Indeed, on this supposition, as soon as there was a violent rain the lightning would cease, and the fluid would pass off by the drops, illuminating the air by its passage from drop to drop.

There seems to be no other mode of considering lightning, than as an explosion, that is, as a sudden production of a great quantity of the electric fluid; the fluid which is then manifested not existing as such but just before we perceive its effects; just as the vapour, of which the clouds are formed, do not exist as vapour in the air until the moment of their appearance: the air, as yet transparent, contained neither the vapour of which the cloud is formed, nor the electric fluids, but the ingredients proper to give birth to both of them. By some cause, of which we are ignorant, clouds of a certain kind are formed. During the progress of their formation, and by fits, the electric fluid is produced in great abundance, and explodes every time it is thus produced. Observations made among mountains where clouds are formed, point out this to be the result of the phenomena.

In a storm observed by M. *de Luc* on the Buet, he had on opportunity of observing this phenomenon with all its modifications. The air of the strata where he was situated was perfectly transparent and dry; the thermometer at 6 of *Reaumur*. Notwithstanding this, clouds formed here and there: by degrees they augmented, then became united, embracing the summit of the Buet, and supporting themselves against Mont Blanc, and the summits of the neighbouring mountains. M. *de Luc* and his companions were inundated with rain: though the clouds and rain formed a complete conductor, communicating with the ground, yet there was a continuance of thunder for a considerable time, and often very violent. Other instances may be found in the works of M. *de Saussure* of thunder storms, where the clouds formed a conducting communication with the ground, and yet where the thunder succeeded without interruption.

The rumbling noise of thunder has been explained by a supposed analogy between the passage of lightning and the electric spark through the air. This explanation might have been admitted as plausible, if the rumbling noise of thunder had grown weaker and weaker, as being a succession of sounds proceeding successively from points more and more distant; whereas the sound of thunder often increases, and gives us a distinct perception of its proceeding from points which are nearer to us than those from which it set out. It is sometimes intermingled with such terrible claps, as deprive the hypothesis of all probability; or other inconsistencies therein might be pointed out. The rumbling and repeated echoes, &c. of thunder still remain among the phenomena not yet accounted for.

In general, a course of hot weather precedes a thunder-storm; and it seldom happens, that very hot weather in the summer terminates without a storm of thunder. Hence also in the East and West Indies, where the climate is so much hotter, thunder and lightning are not only much more frequent, but much more violent, than in this country.

OF WINDS.

Of winds, the observation of our Saviour is still just: we hear the sound of the wind as it passes by, but we neither know whence it comes, nor whither it goes; we cannot determine how it originates, or why it ceases. The great *Bacon* indeed was of opinion, that by a close and regular history of the winds, continued for a number of ages together, and the particulars of each observation reduced to general maxims, we might at last come to understand the variations of this capricious element, and be able to foretel the certainty of a wind with as much ease as we now foretel the return of an eclipse. Indeed his own beginnings in this arduous task seem to speak the possibility of its success; but unfortunately this investigation is the work of ages, and we want a *Bacon* to direct the process.

In the Historia Ventorum, *Bacon* reckons three sources of winds; one by descent from the superior regions of the atmosphere, another from the expansion of the lower air, and a third by exspiration from the earth: of which last he proposes it as an object of inquiry, What winds blow out of subterraneous caverns? Whether they come forth in a large body, or blow insensibly here and there; and then unite in one stream, like a river formed out of many different springs? This latter cause has been but little attended to, though this reciprocation between the earth and air is surely a very interesting part of natural philosophy. In the language of Holy Writ, God is said "to bring the winds out of his treasures;" as if some hidden storehouse were alluded to, such as that of the waters and cavities between the earth.

The annual revolution of the *sun* is doubtless a general cause of winds; but this cause, considered alone, should produce regular winds, whose progress would correspond to, and be connected with the seasons; but the phenomena observed by no means enable us to perceive this connexion. There is another cause, of which we may form an imperfect idea, by which the winds, proceeding from the south, may be south-west to us, and those which come from the north, north-east. This cause is the difference in the velocity of the motion of the parts of the earth we inhabit, and that at the equator, or polar circles. If the air was calm at the equator, that is, moved with the same velocity as the earth, and that in coming from thence to us in the same direction, preserving at the same time a portion of its acquired motion, it would gain upon the earth in this direction, and would thus become south-west. The same cause inverted would change the north for us into a north-east wind. Another cause, though very inconsiderable, may be found in the different diurnal positions of the sun: this, in calm weather, often occasions a gentle east wind after sun-rising, and a west wind after his setting.

Of these causes we have some knowledge; but there must be many, and more powerful ones, to produce those phenomena to which we are continual witnesses, and to which these seem to have little or no affinity. Evaporation and rain have been considered as causes; but they are also by no means adequate to the purpose. Evaporation is constantly operating; it is also more abundant in those places where the heat is greatest. These places are continually varying; but still the variations in evaporation are so slow, and the differences in heat so insensible from one place to another, that it can never occasion any sudden and violent wind. Rain, which is the inverse of evaporation, operates with more rapidity: but the same reasons which prove that rain cannot be formed of the immediate product of evaporation, also prove, that the precipitation of this product, in any stratum of air, cannot make a sufficient vacuum to cause the surrounding air to press in with violence.

We must then have recourse to some other cause to explain the winds which accompany the rapid formation and destruction of clouds; and this may be found in the return of air to a state of vapours. It is known from experiment, that in similar cases there is a great increase of volume in the new fluid; as in the sudden explosion of inflammable air with vital or common air. When the air is changed into aqueous vapour in the atmosphere, there is probably a considerable expansion of the stratum where this change happens, and the effect is more or less extensive in proportion to the strength of the cause. If the production of the clouds be slow, if it embraces a very great portion of the atmosphere, and if the operation be carried on at a great height, but little agitation will be perceived in the air under these strata: the columns thereof extending lengthwise, produce in distant countries winds, of which the inhabitants can no more perceive the causes, than those near which it originated. But if the clouds are formed rapidly, if they occupy but a small space and are not very high, violent winds may be occasioned by the sudden expansion of the medium where they are formed. As the quantity of vapour that is the immediate product of the evaporation is always very small, the formation of drops of rain, on the common system, would only produce insensible and trifling motions of the air. But in M. *de Luc*'s system, the successive production of vapour in the midst of the air is unlimited: their accumulation in the form of vesicles may be immense; and when they are resolved into drops, a considerable vacuum is the natural consequence.

From this view of the origin of winds, we may see also why, in a season of storms and showers, a cold heavy cloud, passing over the head with a hasty fall of snow or hail, is often attended with a sudden violent gust of wind, such as sailors call a squall, which subsides into a calm with the departure of the cloud; till another cloud, coming in the same direction, brings a fresh blast. No tempest, hurricane, or whirlwind, ever happens under a cloudless sky. We hence may perceive why a whistling or howling noise of the wind is the most infallible prognostic of rain, indicating the formation of rainy clouds. The sacred scripture seems to agree with this; for the prophet *Elijah*, before any other symptom of the weather appeared, seemed to give notice to *Ahab* from this one: " Get thee up, and eat and drink, said he, for there is a *sound* of abundance of rain." Then it follows, " that the heaven was soon black with clouds and wind, and there was a great rain."

OF TRADE-WINDS AND MONSOONS.

There are many parts of the world where the winds, that with us are so uncertain, pay their stated visits. In some places, the winds are found to blow one way by day, another by night; in others, for one half the year, they go in a direction contrary to their former course: but what is more extraordinary, there are some places where the winds never change, but for ever blow the same way. This is particularly found to obtain between the tropics in the Atlantic ocean and great Pacific sea.

Between the limits of 60 degrees, namely, from 30° of north latitude to 30° of south latitude, there is a constantly easterly wind throughout the year, blowing on the Atlantic and Pacific oceans; and this is called the *trade-wind*.

The trade-winds near the northern limits blow between the north and the east; and near the southern limits, they blow between the south and the east.

These general motions of the wind are disturbed on the continent, and near the coasts.

Beyond the northern limit of the general wind, on the Atlantic ocean, the westerly winds prevail, but not with any certainty of continuance.

In the Atlantic ocean, the S.E. trade-wind extends as far as three degrees north; and the N.E. trade-wind ceases at the fifth degree N. In the intermediate space are found calms with rain, and irregular uncertain squalls attended with thunder and lightning: but this space is shifted farther to the northward or southward, according as the sun's declination is more northerly or southerly.

In the Indian ocean there are periodical winds, called *monsoons,* that is, such as blow six months in one direction, and the other six months in an opposite direction; the change of their direction, which is near the autumnal and vernal equinoxes, is accompanied with violent storms of wind, thunder, and lightning. Voyagers to India endeavour to time their voyages, so as to benefit by these winds.

On or near the coast of Guinea the winds blow almost always from the west and south-west points. Between the Cape Verd and the easternmost of the Cape Verd islands, there is a tract of sea, which is a perpetual calm with respect to wind; but the thunder and lightning there is terrible.

The varieties and deviations both in general and particular winds are far from being known; you cannot, therefore, expect any theory that will solve them all; there are difficulties which perplex every hypothesis that has hitherto been suggested, and that cannot be cleared up at present.

The best account we have of the trade-winds is that of Mr. *Dalton*,* namely, That as the heat is always greatest in the torrid zone, and decreases in proceeding northward and southward, with respect to these, the poles may be always considered as centers of cold; so that, abstracting from accidental circumstances, there must be a constant ascent of air over the torrid zone, which afterwards falls northward or southward, whilst the colder air below is determined by a constant impulse towards the equator. In general, where the heat is greatest, the heated air will ascend, and a supply of colder air will be received from the neighbouring parts.

The following effects may be attributed to the diurnal motion of the earth; the air over any part thereof, when calm, will have the same rotatory velocity as that part; but if a quantity of air in the northern hemisphere receive an impulse in the direction of the meridian, either northward or southward, its rotatory velocity will be greater in the former, and less in the latter case, than that of the air into which it moves; consequently, if it move northward, it will have a greater velocity eastward than the air, or surface of the earth over which it moves, and will therefore become a S.W. wind, or a wind between the south and the west; and, *vice versa*, if it move southward, it becomes a N.E. wind. Likewise in the southern hemisphere it will appear, the winds, upon similar suppositions, will be N.W. and S.E. respectively.

From this view of the air, Mr. *Dalton* attempts to explain the trade-winds; he considers two general masses of air, as proceeding from both hemispheres towards the equator; these, as they advance, are constantly deflected more and more towards the east, on account of the earth's rotatory motion. That from the northern hemisphere, originally a north wind, is made to veer more and more towards the east; and that from the southern hemisphere is made to veer from the south towards the east: these two masses meeting in the torrid zone, their north and south velocities destroy each other, and they proceed with their common velocity from east to west round the torrid zone. The equator is not the center of the concourse, but the northern parallel of 4°, because the center* of heat is at that place, the sun being longer on the north side of the equator than on the south side. Though all the parts of the atmosphere seem to conspire in producing regular winds round the torrid zone, yet, from the situation of the land or other causes, striking irregularities are produced, as is evident from the monsoons, sea and land breezes, &c. these are deviations from the general rule, but this will ever be more or less the case with all human theories.

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* *Dalton*'s Meteorological Observations.

To explain the monsoons, it is necessary to attend to the circumstances that are peculiar to the Indian ocean, and which are not found in the Atlantic and Pacific oceans. They seem to be these: that the Indian ocean is bounded to the northward by shores, whose latitude does not exceed the limits of the general trade-wind; and that the general trade-wind falls on what sailors term lee shores to the westward.

The sun being twice a year vertical in the equator, and never departing thence more than 23½ degrees, causes the air in that climate to be hotter than at any other place in the ocean: such a rarefied space must extend across the Indian ocean, and produce a S.E. wind to the southward, and a N.E. wind to the northward of the equator, over which, in the upper regions of the air, the winds return in the

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[*] *Prevost* sur les Limites des Vents Alizes.

contrary direction. This we accordingly see happen in the months of October, November, December, January, February, and March. But when the sun declines to the northward, and heats the land there, the air contiguous to those lands is rarefied, and the lower air has a tendency to move that way: this tendency increases as the sun advances further north, so that the whole body of the lower air, to the northward of the equator, moves towards the northern lands, notwithstanding the equatorial rarefaction. It seems then, that the body of the lower air in the northern part of the Indian ocean is determined, as to its course, by the greater rarefaction. If the rarefaction at the surface of the land be greater than that at the equator, the wind blows to the north; and the contrary happens when the equatorial rarefaction is the greatest.* Thus it appears, that it is the situation of the lands, and their effect in heating and rarefying the atmosphere, which are the principal causes of the monsoons. Still, however, it must be owned, that the explanation is imperfect, and the observations we possess too few to form a theory. In the commencement of the monsoons, to use the seamen's phrase, they creep along the shore, they then spread into the ocean: at first they are feeble, they afterwards become vigorous; they then gradually diminish, and finally come to a change; and this twice in a year, agreeable to our solar progress.

The sun is the undoubted cause of the sea and land breezes, which are wisely appointed by Divine Providence to make some of the hotter climates habitable. The sea breezes in the West Indies begin to appear about nine o'clock in the morning, in a fine black curl upon the water, approaching the shore; it increases gradually till noon, and dies away at four or five in the afternoon. About six in the evening it changes to a land breeze, which blows from the land to the sea, and lasts till eight in the morning. There is an interval in the morning and evening between the changing of the breezes, when the wind is stationary, like the water before turning of the tide; and these intervals are the hottest parts of the day.

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* *Nicholson's* Philosophy, vol. ii. p. 61 and 62.

The breezes are thus accounted for: when the sun is up, his heat takes more effect on the land than on the water, so that the heat is accumulated, and the air over the land is rarefied; and as it mounts upward, the colder air from the sea comes in to keep up the equilibrium. In the evening the dews are so excessive, and the cold so sudden on the land, from the quick descent of the sun below the horizon, that the water in the night is warmer than the land; and the air of the sea, being then most rarefied, the draught of air is contrary to what it was in the day.

In the northern temperate zone the winds are variable, but the most general are the S.W. and W. and the N.E. and E. In the northern temperate and frigid zones, the winds are more tempestuous in winter than in summer.*

" In our climates, a tempest is but rarely known, and its ravages are registered as an uncommon calamity; but, in the countries that lie between the tropics, and for a good space beyond them, its visits are frequent, and its effects anticipated. In these regions the winds vary their terrors, sometimes involving all things in a suffocating heat; sometimes mixing all the elements of fire, air, water, earth together; sometimes with a momentary swiftness passing over the face of the country, and destroying all things in their passage; and sometimes raising whole sandy deserts in one country, to deposit them in another. We have, therefore, very little reason to envy those climates, the luxuriance of their soil, or the brightness of their skies. Our own cloudy atmosphere, that wraps us round in obscurity, though it fails to gild our prospects with sunshine, or our groves with fruitage, nevertheless answers the calls of industry; the labourer toils in the certain expectation of a moderate but happy return."

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* *Dalton*'s Meteorological Observations, p. 88.

The rains in the West Indies are by no means the things they are with us. Our heaviest rains are but dews comparatively: they are rather floods of water, poured from the clouds with a prodigious impetuosity; the rivers rise in a moment; new rivers and lakes are formed; and in a short time all the low countries are under water.

It is in the rainy season, principally in the month of August, that they are assaulted by hurricanes, which destroy at a stroke the labours of many years, and prostrate the most exalted hopes of the planter, and that often when he thinks himself out of the reach of fortune. It is a sudden and violent storm of wind, rain, thunder, and lightning, attended with a furious swelling of the seas, and sometimes with an earthquake; in short, with every circumstance which the elements can assemble that is terrible and destructive. First they see, as a prelude to the ensuing havock, whole fields of sugar canes whirled into the air, and scattered over the face of the country. The strongest trees of the forest are torn up by the roots, and driven about like stubble; their wind-mills are swept away in a moment; their works, the fixtures, the ponderous copper-boilers and stills of several hundred weight, are wrenched from the ground and battered to pieces; their houses are no protection; their roofs are torn off at one blast, whilst the rain, which in an hour rises five feet, rushes in upon them with irresistible violence.

There are signs by which the Indians of these islands taught our planters to prognosticate the approach of an hurricane. The hurricane comes on either in the quarter or at the full change of the moon. If it comes on at the full, then at the preceding change the sky is troubled, the sun more red than usual; there is a dead calm below, and the mountain tops are free from those mists which usually hover about them. In the caverns of the earth and in wells, you hear a hollow rumbling sound, like the rushing of a great wind. At night the stars seem much larger than usual, and surrounded with a sort of burs; the north-west sky has a black and menacing appearance; the sea emits a strong smell, and rises into vast waves often without any wind. The wind itself now forsakes its usual steady easterly stream, and shifts about to the west, from whence it sometimes, with intermissions, blows violently and irregularly about two hours at a time. You have the same signs at the full moon; the moon herself is surrounded with a great bur, and sometimes the sun has the same appearance.

The nature of the soil over which the wind blows has a great effect upon the quality of the air: the vast sandy deserts of Africa and Arabia give a burning heat and blasting quality to the air that passes over them. These horrid regions lie to the southward and eastward of the Mediterranean; and hence it is that travellers, who have had the opportunity of making the comparison, tell us, that the air of the West India islands is nothing to the hot suffocating winds which blow in the night at Minorca and Gibraltar, for these latter are scarcely supportable by the human frame. At Goree, in the river Senegal, there is an easterly wind from the inland parts, with which those who are suddenly met by it in the face are scorched up as by a blast from a furnace.

An extraordinary blasting wind is felt occasionally at Falkland Islands. Happily its duration is short; it seldom continues above twenty-four hours. It cuts the herbage down as if fires had been made under them; the leaves are parched up and crumble into dust; fowls are seized with cramps, so as never to recover; men are oppressed with a stopped perspiration, heaviness at the breast, and sore throat, but recover with care.

But, beyond all others in its dreadful effects, is the *samiel*, or mortifying wind, of the deserts near Bagdad. The camels, either by instinct or experience, have notice of its approach, and are so well aware of it, that they are said to make an unusual noise, and cover up their noses in the sand. To escape its effects, travellers throw themselves as close as possible to the ground, and wait till it has passed by, which is commonly in a few minutes. As soon as they who have life dare to rise again, they examine how it fares with their companions, by plucking at their arms or legs; for, if they are destroyed by the wind, their limbs are absolutely mortified, and will come asunder. It is said of this wind, that if it happens to meet with a shower of rain in its course, and blows across it, it is at once deprived of its noxious quality, and becomes mild and innocent. It is also said, that it was never known to pass the walls of a city.

OF THE AURORA BOREALIS.

No person has paid so much attention to this subject as Mr. *Dalton*; he is also the only one that I know of who has given a clear and satisfactory account of this phenomenon. To this work I must refer you; contenting myself here with laying before you his account of the appearances of the aurora borealis, without entering into his explanation thereof.

The appearances of the aurora come under four different descriptions. 1. A horizontal light, like the morning aurora, or break of day. 2. Fine slender luminous beams, well defined, and of dense light. These often continue a quarter, an half, or a whole minute apparently at rest, but oftener with a quick lateral motion. 3. Flashes pointing upward, or in the same direction as the beams, which they always succeed. These are only momentary, and have no lateral motion; but they are generally repeated many times in a minute. They appear much broader, more diffuse, and of a weaker light than the beams: they grow gradually fainter till they disappear; and sometimes continue for hours flashing at intervals. 4. Arcs, nearly in the form of a rainbow; these, when complete, go quite across the heavens, from one point of the horizon to the opposite point.

When an aurora happens, these appearances seem to succeed each other in the following order: 1. the faint rainbow-like arcs; 2. the beams; and 3. the flashes. As for the northern horizontal light, it appears to consist of an abundance of flashes or beams blended together by the situation of the observer.

The beams of the aurora borealis appear at all places to be arcs of great circles of the sphere, with the eye in the center; and these arcs, if prolonged upwards, would all meet in one point.

The rainbow-like arcs all cross the magnetic meridian at right angles. When two or more appear at once, they are concentric, and tend to the east and west: also the broad arc of the horizontal light tends to the magnetic east and west, and is bisected by the magnetic meridian; and when the aurora extends over any part of the hemisphere, whether great or small, the line separating the illuminated part of the hemisphere from the clear part, is half the circumference of a great circle crossing the magnetic meridian at right angles, and terminating in the east and west: moreover, the beams perpendicular to the horizon are only those on the magnetic meridian.

That point in the heavens to which the beams of the aurora appear to converge, at any place, is the same as that to which the south pole of the dipping needle points at that place.

The beams appear to rise above each other in succession; so that of any two beams, that which has the higher base, has also the higher summit.

Every beam appears broadest at or near the base, and to grow narrower as it ascends; so that the continuation of the bounding lines would meet in the common center to which the beam tends.

The height of the rainbow-like arcs of the aurora are estimated by Mr. *Dalton* to be above the earth's surface about 150 English miles.

OF THE SOURCES OF HEAT AND COLD.*

If the changes of the weather depended on the course of the year, and the temperature of climates were governed by their situation with respect to the sun, that is, by their latitude, then the weather might be reduced to some regular theory. But this is so far from being the case, that the latitude of a place cannot be considered as an index to the temperature of the climate: for we find the hottest days in the coldest climates; and the coldest weather, and even perpetual snow, are found in countries bordering on and immediately under the equator: so that we must recur to some other causes besides the immediate influence of the solar rays.

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* *Kirwan*'s Estimate of the Temperature of different Latitudes. *Jones*'s Physiological Disquisitions.

1. But though the sun is not the only cause, its presence is undoubtedly the principal source of heat as well as light, and its absence the primary cause of cold. He is indeed the great spirit of the world: all things revive at his approach; winter and frost lay behind him.

2. The second source of heat is the earth. Nobody has yet been found so absurd as to suppose that human perspiration was owing to the air that surrounds the skin; it originates in an internal cause; it is occasioned by a heat within, not the air without. It is the same with respect to the earth; which, by imparting its heat to the atmosphere, moderates the rigour of the winter's cold. Whether we suppose that this heat arises from a central source, or that the globe from its first creation was endued with a heat sufficient for all the purposes it was intended to answer; yet it is evident that it is renewed and preserved by the influence of the sun, and that there is always a silent and imperceptible heat proceeding from the earth.

M. *de Luc* shews, that our globe has a provision of fire spread through its whole mass; so that, wherever there is no chemical operation to disengage or to absorb it, this fire maintains the same degree of expansive force. From observation we also find, that the same degree of heat reigns in all subterraneous places, except in mines, where there is reason to suspect some chemical operation. With respect to those parts of the globe which are nearest the surface, the fire passes therefrom into the air, when its expansive force exceeds that of the fire in the air, and *vice versa*. Thus a certain equilibrium is preserved near the surface, though subject to certain vicissitudes.

The solar rays exercise two distinct functions; in the one acting as fire, in the other increasing the expansive force of the existing fire. Various combinations of fire are continually forming, as well upon the surface of the globe as in the atmosphere; combinations which are afterwards under other circumstances destroyed. These compositions and decompositions occasion the greater part of terrestrial phenomena.

3. The next great source of heat is the condensation of vapour. Vapour contains a quantity of fire: it is this fire which causes it to assume, and supports it in an aerial expanded state; when condensed into a liquid form, it lets go this fire, which warms the surrounding atmosphere: hence the sultriness frequently experienced before rain.

OF THE SOURCES OF COLD.

1. As the earth is one of the principal sources of heat in the atmosphere that surrounds it, so is distance from the earth a source of cold; the greatest cold prevailing in the highest regions of the atmosphere: for, where the re-action is wanting by a superficial pressure, but little effect can be received from the rays of the sun; and it is further proved by experiments with a burning glass, that a clear unclouded air receives no heat from these rays. Hence, when we ascend to a lighter air, at a distance from the surface, the heat is not sufficient to melt the snow; and we find the highest mountains, even under the equinoctial, perpetually covered therewith: thus, the mean height of the lower term of congelation in winter, in this latitude, may be considered in general to be at 6260 feet from the surface, and the mean height of the upper term at 1125 feet. We cannot in this Lecture consider any of the minute exceptions.

Sir *William Young* gives a remarkable instance of the effect of hills in arresting vapours and producing rain, while the exhalations from the trees on its surface cool and temper the air; observing, that the smooth polished Barbadoes and our Leeward Islands are parched up, whilst the towering and rugged Dominica, St. Vincent, Grenada, and Tobago, enjoy incessant rains and delicious verdure.

It is generally agreed, that the clearing away of wood in time lessens the vapours, and consequently the rain of a country. Several fine parishes in Jamaica, which used to produce large crops of sugar canes, and were once the richest spots in the island, are now dry for nine months in the year, and are turned into cattle-pens, through the clearing away of the neighbouring woods.

Water is very plentiful in those countries where woods and forests abound, and the purest springs are generally found beneath the friendly shelter of a grove.

The natural history of every country shews, that in proportion as the woodlands are cleared, the water courses diminish.

In America, unfortunately for the inhabitants, this truth is too well known; for, since the woods in the vicinity of their towns have been cut down, many long established mill races have become dry, and others have been reduced so low, as to cause very great interruptions to the miller, who must wait a considerable time for the dams to fill between every few hours work.

Hence we may learn the important necessity of preserving the trees, from beneath whose humid shades a water spring discharges its streams; and hence, too, we may learn, that the smallest springs may be improved by planting around them a grove of trees, particularly the oak, so highly valued by the Greeks, the Romans, and our ancient Druids; who, considering the health of man and the fertility of the soil to be absolutely dependent upon plenteous streams of water, consecrated their groves to preserve their springs.

2. The next great source of cold is evaporation. The same cause which makes the condensation of vapour a source of heat, makes evaporation productive of cold; as it absorbs the fire in the latter instance, which it gives out in the former: it is this which gives the particles of vapour their aerial form. When fire passes from fluids which it has heated, its course is upwards, and it always carries with it a thin stratum of the fluid in the form of vapour: thus evaporation not only tempers the heat occasioned by the sun's rays, but is one great source of cold.

OF EVAPORATION.

Of evaporation it may be observed, 1. That in our climates the quantity of it is four times greater from the 21st of March to the 21st of September, than it is from the 21st of September to the 21st of March.

2. That it is greater in proportion as the difference in temperature between the air and evaporating surface is greater; though, if the air be 15 degrees colder than the evaporating surface, there is no evaporation, but a deposit of moisture from the air.

3. The degree of cold produced by evaporation, is always much greater when the air is warmer than the evaporating surface, than that which is produced when this surface is warmer than the air. Hence warm winds, as the Serocco and Harmatan, are more desiccative than cold winds.

4. Evaporation is more copious when the air is less loaded with vapours, and is consequently powerfully promoted by cold winds flowing into warmer countries.

5. That it is greatly increased by a current of air or wind flowing over the evaporating surface; not only because the evaporating surface is thereby increased, but also because the vapour is thereby removed, and prevented from attaining its maximum: hence it is generally remarked, that calm days are the hottest.

6. Tracts of land covered with trees or vegetables emit more vapour than the same space covered with water: on this principle it is, that the air about a wood or forest is made colder by the evaporation from trees and shrubs, while the plants themselves are kept in a more moderate heat, and secured from the burning heat of the sun by the vapour perspired from the leaves. Thus, we find the shade of vegetables more effectual to cool us, as well as more agreeable, than that from rocks and buildings.

7. The heat and cold of different countries are transmitted from one country to another by the medium of winds.

OF ANNUAL TEMPERATURE.

Within ten degrees of the pole, there is very little difference in the annual temperature, nor is there much within ten degrees of the equator.

The temperature of different years differs very little near the equator, but they differ more and more as their latitudes approach the pole.

It scarce ever freezes, unless in very elevated situations, in latitudes under 35°; and it scarce ever hails in latitudes higher than 60°.

Between the latitudes of 35° and 60°, in places adjacent to the sea, it generally thaws when the sun's altitude is 40°, and seldom begins to freeze until the sun's meridian altitude is below 40°.

The greatest cold in all latitudes in our hemisphere is generally about half an hour before sun-rise:

the greatest heat in all latitudes between 60° and 45° is found to be about half past two o'clock in the afternoon; between latitudes 45° and 35°, at two o'clock; between latitudes 35° and 25°, at half past one; and between latitude 25° and the equator, at one o'clock.

The month of January is the coldest in every latitude. July is the warmest month in all latitudes above 48°; but in lower latitudes, August is generally the warmest.

December and January differ but little, and there is no great difference between June and July. In latitudes above 30°, the months of August, September, October, and November, differ more from each other than those of February, March, April, and May; in latitudes under 30° the difference is not so great. The temperature of April approaches more every where to the mean annual temperature than that of any other month: whence we may infer, that the effects of natural causes, operating over a large extent, do not arrive at their maximum until the causes begin to diminish; but that after these effects have arrived at their maximum, the decrements are more rapid than the increments originally were, during their progress to that maximum.

The differences between the hottest and the coldest months, within twenty degrees of the equator, are inconsiderable, except in some peculiar situations; but they increase in proportion as we recede from the equator.

In the highest latitudes, we often meet with a heat of 75° or 80°; and particularly in latitudes 59° and 60° the heat of July is frequently greater than in latitude 51°.

At the time of the equinoxes, when the sun passes from one hemisphere into the other, there is generally some disturbance in the weather; the winds are then mostly higher: at the vernal equinox, they are for the greater part easterly, cold, dry, and searching. The solstitial point of the summer is more apt to be distinguished by violent rains, and what we call a midsummer flood. The winter being less rainy than the summer, nothing particular happens at the winter solstice, except that the frost sets in more severely, with some continuance of snow, which lies long upon the ground.

The temperature of a climate depends on many circumstances, particularly on the disposition of the land; as its elevation, its exposure to the winds, and the course of the mountains that are found in it. Thus the writer of *Anson*'s voyage informs us, that while they coasted near the land of South America, which has those vast ridges of mountains, the Andes and Cordillieras, the air was rendered temperate by the wind that blew over them; but when they had passed beyond this tract of land, and sailed by the isthmus of Darien, where the country is flatter, the air became insupportably close and sultry.

All countries lying to the windward of high mountains, or extensive forests, are warmer than those to the leeward in the same latitude.

The vicinity to the sea is another circumstance which affects the temperature of a climate; as it moderates the heats from the land, and brings the atmosphere down to a standard best fitted to the human constitution. This is probably the reason why there is so great a proportion of sea on the terraqueous globe, and particularly why it is so largely distributed about the middle region of the earth. In our hemisphere, countries that lie southward of any sea, are warmer than those that have that sea to the south of them; because the winds that should cool them in winter are mitigated by passing over the sea; whereas, those that are northward of the sea, are cooled in summer by the breezes from it. A northern or southern bearing of the sea renders a country warmer than an eastern or western bearing.

Islands participate more of temperature arising from the sea, and are therefore warmer than continents. Most large islands have their greatest extent from north to south. With us, the southern parts are proportionably colder than the northern. A ridge of mountains generally traverses islands in the direction of their length.

The soil of large tracts of land has its share in influencing the temperature of the weather: thus, stones or sand heat and cool more readily, and to a greater degree, than the earth or vegetable mould; hence the violent heats of the most sandy deserts of Arabia and Africa, and the burning heat and blasting qualities of the wind that passes over them: hence also the intense cold of Terra del Fuego, and other stony countries in cold latitudes.

Living vegetables have a considerable effect in altering climates, and affecting the weather. Wooded countries are much colder than those that are open and cultivated; thus, part of Guiana has only been cleared from wood since the beginning of this century, and the heat in that part is already excessive; whereas in the wooded parts, the inhabitants are obliged to light a fire every night.

Every habitable latitude enjoys a heat of 60 degrees at least, for two months; which heat seems necessary for the growth and maturity of corn. The quickness of vegetation in the higher latitudes proceeds from the duration of the sun over the horizon. Rain is little wanted, as the earth is sufficiently moistened by the liquifaction of the snow that covers it during the winter. In all this, we cannot sufficiently admire the wise disposition of Providence.

It is owing to the same provident hand, that the globe of the earth is intersected with seas and mountains, in a manner that on its first appearance seems altogether irregular and fortuitous, presenting to the eye of ignorance the view of an immense ruin: but, when the effects of these seeming irregularities on the face of the globe are carefully inspected, they are found most beneficial, and even necessary to the welfare of its inhabitants; for, to say nothing of the advantages of trade and commerce, which could not exist without these seas, we have seen that it is by their vicinity that the cold of the higher latitudes is moderated, and the heat of the lower. It is by the want of seas, that the interior parts of Asia, as Siberia and Great Tartary, as well as those of Africa, are rendered almost uninhabitable; a circumstance which furnishes a strong prejudice against the opinion of those, who think these countries were the original habitations of man. In the same manner, mountains are necessary, not only as the reservoirs of rivers, but as a defence against the violence of heat in the warm latitudes. Without the Alps, Pyrenees, Apennine, the mountains of Dauphine, and Auvergne, &c. Italy, Spain, and France would be deprived of the mild temperature they at present enjoy: without the Balgate hills, or Indian Apennine, India would have been a desert: hence Jamaica, St. Domingo, Sumatra, and most other intertropical islands, are furnished with mountains, from which the breezes proceed that refresh them.

OF ATMOSPHERICAL ELECTRICITY.

So little is known with any certainty concerning atmospherical electricity, that I shall detain you but a short time with what I have to say thereon. If every solution of continuity, every expansion and contraction of material substances, are sources of electrical appearances, we need not be surprized at finding it in great abundance among the clouds: in this view of the subject, the perpetual oscillations of the air must be also a means of rendering it sensible to us. Mr. *Bennet*'s* electrometer, which I have already described, is the best and readiest instrument for observing the changes in the electricity of the atmosphere.

The following positions have been deduced from some observations on the electrical state of the atmosphere. 1st. That in the spring, when plants begin to grow, we are told that temporary electrical clouds begin to appear, and pour forth electric rain. 2. That the electricity of the clouds and of the rain increases, till that part of autumn, when the last fruits are gathered. It is hence supposed to actuate and animate vegetation, and to give to rain that power which renders it more propitious to vegetables than any other kind of watering.

Aerial electricity varies according to the situation; it is generally strongest in elevated and insulated situations; not to be observed under trees, in streets, in houses, or any inclosed places; though it is sometimes to be found pretty strong on quays and bridges. It is also not so much the absolute height of the places, as their situation; thus a projecting angle of a high hill will often exhibit a stronger electricity than the plain at the top of the hill, as there are fewer points in the former to deprive the air of its electricity.

The intensity of the atmospheric electricity is varied by a great many circumstances, some of which may be accounted for, others cannot. When the weather is not serene, it is impossible to assign any rule for their variation, as no regular correspondence can then be perceived with the different hours of the day, nor with the various modifications of the air.

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* See the Rev. Mr. *Bennet*'s New Experiments on Electricity. Derby, 1789.

The reason is evident; when contrary and variable winds reign at different heights, when clouds are rolling over clouds, these winds and clouds, which we cannot perceive by any exterior sign, influence however the strata of air in which we make our experiments, and produce those changes of which we only see the result, without being able to assign either the cause or its relation. Thus, in stormy weather, we see the electricity strong, then null, and in a moment after arise to its former force; one instant, vitreous; the next, resinous; without being able to assign any reason for these changes. M. *de Saussure* says, that he has seen these changes succeed with such rapidity, that he had not time to note them down.

When rain falls without a storm, these changes are not so sudden; they are, however, very irregular, particularly with respect to the intensity of force; the quality thereof is more constant. Rain or snow almost uniformly gives vitreous electricity.

The state of the air, in which the electricity is strongest, is foggy weather; this is always accompanied with electricity, except when the fog is going to resolve into rain.

The most interesting observations, and those which throw the greatest light upon the various modifications of electricity in our atmosphere, are those that are made in serene weather. In winter, during which most of M. *de Saussure*'s observations were made, and in serene weather, the electricity was generally weakest in an evening, when the dew had fallen, until the moment of the sun's rising; its intensity afterwards augmented by degrees, sometimes sooner, and sometimes later; but generally before noon it attained a certain maximum, from whence it again declined, till the fall of the dew, when it would be sometimes stronger than it had been during the whole day; after which it would again gradually diminish during the whole night; but is never quite destroyed, if the weather is perfectly serene.

Atmospherical electricity seems therefore, like the sea, to be subject to a flux and reflux, which causes it to increase and diminish twice in 24 hours. The moments of its greatest force are some hours after the rising and setting of the sun; those, when it is weakest, precede the rising and setting thereof.

The electricity of serene weather is much weaker in summer than in winter, which renders it more difficult to observe these gradations in summer than in winter; besides a variety of accidental causes, which at the same time render them more uncertain. In general, in summer, if the ground has been dry for some days, and the air is dry also, the electricity generally increases from the rising of the sun till three or four in the afternoon, when it is strongest; it then diminishes till the dew begins to fall, which again re-animates it; though after this it declines, and is almost extinguished during the night.

But the serene days that succeed rainy weather in summer, generally exhibit the same diurnal periods or states of electricity, as are to be observed in winter.

ON PROGNOSTIC SIGNS OF THE WEATHER.

There is no part of meteorology which interests mankind so much, as the predictions it furnishes of the change of weather. The theory of it only engages the attention by animating us with the hopes of thereby bringing the knowledge of these predictions to perfection.

And the far greater part of those who purchase meteorological instruments, buy them, not so much to know the actual state of the elements, as to foresee the changes thereof. This science is, however, very imperfect; for it is but of late years that we began to make observations on the changes of the weather; and that its progress has been rapid and successful may be seen in the works of *De Luc*, *De Saussure*, *Jones*, *Marshall*, and *Kirwan*. But these observations will be still more valuable to posterity; for we can scarce expect them in sufficient number in our own age to deduce from them a general and perfect theory.

To attain this end it will be necessary to multiply observations on as great a number of signs as possible; for it is only by their combination and concurrence that we can expect to remove the uncertainty inseparable from each in itself. Thus the barometer is not always a certain sign; the same may be said of the thermometer, the hygrometer, and the action of winds. But if they all concur together, there is but little chance of being deceived; and there would be still less, if to these were joined other signs, which are easy to observe, and which, by their combination would render our prediction certain.

No sign, nor any instrument of observation, should therefore be neglected, either from a love of ideal perfection, or fears of inaccuracy. Thus, though the hygrometer be at present a very imperfect instrument, yet one certain sign has already been obtained from its indications, and more may be reasonably expected. Even the words *very dry*, *very moist*, *moderately dry*, *moderately most*, though of vague determination, may throw much light on the state of the atmosphere.

It is necessary that the observer should enter into a precise detail of the various states of the sky and the clouds. What can we learn from the words *covered*, and *cloudy*, or *half covered sky*, &c.? Nothing; since it is well known, that a covered sky, in one case, is almost as certain an indication of fine weather, as in another it is an indubitable presage of rain. The accurate observer piques himself on a thermometer, with which he can observe within a degree, and a barometer that he can depend upon to less than the hundredth of an inch; but is silent on the transparency of the air, on dews, on the elevation, the form, the sign, the disposition, the colour, and the density of the clouds; things that may be observed with ease, and described without trouble; being attended with no other inconvenience than that of extending the size of our meteorological tables.

There is a phenomenon which has not been sufficiently attended to, namely, the undulating motion of the firmament, or that diurnal tumult in the air, whick is kept up by the heat of the sun. What the sun raises from the earth by the heat of the day, is sustained in the atmosphere by its heat, and the agitation, or expansive undulation of the air. This motion is often visible to the naked eye, but in the field of a powerful telescope it is very conspicuous; all objects appear in violent agitation, and the line of the sensible horizon, which ought to be clear and well defined, is waved like a field of corn in the wind, or the surface of the sea in a storm. So long as this agitation continues, the vapours stay in the air; but when it subsides, and the sun departs, they are condensed, and fall down to the earth in the night as dew.

In the present state of this part of science, when we are unacquainted with so many phenomena, and still more ignorant of their causes, general rules will often be found to fail, and particular ones will, without much circumspection, prove to be a source of error. Amongst the variety of means for predicting the changes of the weather, the barometer is undoubtedly one of the best; and is in this, as well as many other respects, one of the greatest acquisitions to natural philosophy.

The usual ranges of the mercurial column in this latitude are comprized between 28 and 31 inches, of which the middle, or 29½, is considered as the variable: I think it should be placed somewhat higher. Near the pole, the variations of the barometer are much greater.

OF PROGNOSTICS BY THE BAROMETER.

Ever since the barometer has been invented, philosophers have endeavoured to account for the variations in the height of a local barometer, but hitherto in vain. M. *de Luc*, in the first volume of his Recherches sur les Modifications de l'Atmosphere, has given a critical and very interesting account of the various physical opinions that have been invented for this purpose by *Pascal*, *Beale*, *Wallis*, *Garden*, *Halley*, &c. &c. and shewn that they are all imperfect, and inadequate to the solution of the phenomena. He then proposes one of his own; which with that candour that ever distinguishes a lover of the truth he has since abandoned. To give a particular account of the various hypotheses would occupy a volume, and that to little purpose. As I know of none that can be depended on, I shall content myself with only relating the bare phenomena. The two great sources of error on this subject have been, 1st. The difficulty of observing the whole of the appearances; and 2dly, The facility with which the mind embraces and supports a favourite hypothesis.

There is one striking phenomenon in the variations of the barometer, which should be particularly attended to in every theory, because it is as great as it is certain and invariable; namely, that the variations diminish in proportion as you approach the equator, and augment as you advance towards the poles. The countries, however, that are situated about the equator, are subject to the changes of the weather, though it is more constant there than in the temperate climates: there are changes there of humidity and dryness, rains and fair weather, storms and tempests, &c. much more violent than with us; and yet all these take place without any way affecting the barometer.

MR. DALTON'S GENERAL RULES AND OBSERVATIONS FOR JUDGING OF THE WEATHER.

1. The barometer is highest of all during a long frost, and generally rises with a N.E. wind; it is lowest of all during a thaw following a long frost, and is often brought down by a S.W. wind.

2. When nearest the high extreme for the season of the year, there is very little probability of immediate rain.

3. When the barometer is low for the season, there is seldom a great weight of rain, though a fair day in such a case is rare. The general tenor of the weather at such times is, short, heavy, and sudden showers, with squalls of wind from the S.W.W. or N.W.

4. In summer, after a long continuance of fair weather, with the barometer high, it often falls gradually, and for one, two, or more days before, there is much appearance of rain. If the fall be sudden and great for the season, it will probably be followed by thunder.

5. When the appearances of the sky are very promising for fair weather, and the barometer at the same time low, it may be depended upon that the appearances will not remain such long. On these occasions the face of the sky changes very suddenly.

6. Very dark and dense clouds pass over, when the barometer is high, without rain; but when the baro-

meter is low, it sometimes rains almost without any appearance of clouds.

7. All appearances being the same, the higher the barometer is, the greater is the probability of fair weather.

8. Thunder is generally preceded by hot weather, and followed by cold and showery weather.

9. A sudden and extreme change of the temperature of the atmosphere, either from heat to cold, or cold to heat, is generally followed by rain within 24 hours.

10. In winter, or during a frost, if it begins to snow, the temperature of the air generally rises to 32°, and continues there while the snow falls; after which, if the weather clears up, expect a severe cold.

11. The aurora borealis is a prognostic of fair weather.

FURTHER INDICATIONS OF THE WEATHER BY THE BAROMETER.

In general, when the barometer falls, there is rain; but when the mercury rises, it is a sign of fair weather.

If the mercury falls in a frost, we may expect snow, or a thaw; but if it rises in winter, with a north or east wind, it generally portends a frost.

If the mercury sinks slowly and gradually, we may expect that the rain will be of some continuance; and if the rise be gradual, we may judge that the fine weather will be lasting. If it fluctuates much, rising and falling suddenly, the weather is unsettled and changeable: if it falls very low, there will be much rain; but if its falls are low and sudden, a high wind generally ensues: when exceeding low, storms and tempestuous weather may be expected; but if an extraordinary fall happens, without any remarkable change near at hand, it is probable, that there is a storm at a distance.

The descent of the barometer is not, however, always an indication of rain, for it will often fall for wind; nor is its rise a certain sign of fair weather, particularly if the wind be northerly or easterly. If the fine weather be lasting, with a westerly wind, the mercury generally rests a little above changeable, but somewhat below thirty inches.

In the summer months the barometer does not vary so much as in winter; the greatest variations are in the first two, and the last two months of the year, but particularly in the first and last. A north-east wind generally makes the barometer in this country rise, and it is generally lowest with a south-westerly wind.

If the mercury continues to fall while it rains, it will be likely to rain the next day: when the mercury is pretty high, and has fallen to foretel rain, and yet rises before the rain falls, it is an indication that there will be but little. In fair weather, when the mercury has continued high and rising, if it falls about noon, and rises again towards the evening, a single shower may be expected on the evening or noon of the next day, and then fair weather. When the mercury rises gradually about half a tenth, and continues to do so for many days, the fair weather may be expected to continue for some time, unless wind intervenes, particularly from the S.W. by S.

FROM THE THERMOMETER.

In winter, if the cold diminishes suddenly, it in general portends rain; in summer, a sudden augmentation of heat is also a forerunner of rain.

FROM THE BAROMETER AND THERMOMETER.

If the air in foggy weather becomes hotter by the action of the sun alone, the fog generally dissipates and the air remains serene: but if the barometer falls, and the change of temperature be from a south or south-west wind, the fog rises and forms itself into clouds, and its ascension is generally a sign of rain.

FROM THE BAROMETER, HYGROMETER, WIND, AND STATE OF THE SKY.

The barometer being high and stationary, the natural and factitious hygrometers indicating dry air, the canopy of the sky lofty, and the wind north-easterly, are the surest signs of settled fair; while a light and moist atmosphere, the canopy of the sky low, and a south-west wind, certainly portend a wet season.

FROM CLOUDS.

When the clouds are formed like fleeces deep and dense towards the middle, and very white at the edges, with a bright blue sky about them, they generally soon fall in hail, snow, or in hasty showers of rain. In the north of England, such clouds are called woolpacks.

There is no sign of rain more certain than two different currents of clouds, especially if the undermost flies fast before the wind; when this happens in summer, there is seldom wind at the time, and thunder generally follows. In winter the light vapour, or scud as the sailors call it, often comes rapidly against the wind, and a gale is soon after expected.

The transparency of the air is to the inhabitants of the Alps one of the most certain signs of rain; when the distant objects appear distinct and well defined, when the sky is of a deep blue, they consider rain as near at hand, though no other signs appear. I have been informed by a gentleman, to whom I am under obligations for other observations, that this sign, from the transparency of the air, is by no means local, but is often observed in England; that in such a state of the air, the sailors say the land, or other object, looms near, and expect bad weather.

When the sky, in a rainy season, is tinged with a sea-green colour, particularly near the horizon, when it ought to be blue, the rain will continue and increase. If it be of a deep dead blue, it will be showery: this is more particularly found to hold true near the sea coast.

Clouds of a similar appearance produce thunder in summer, and snow in winter; such clouds are broken, and irregularly shaped, heaped one on another, and from their uncommon density project towards the earth. After a thunder storm, if it has been of considerable duration, the wind generally, if not always, veers to the quarter from whence the first clap proceeded.

A close sultry day, the current of air scarcely perceptible, is often succeeded by a change in the wind.

The wind shifting from point to point round the compass, generally denotes rain. If, after a continued rain from a muddy sky, the horizon appears lighter in any quarter, expect the wind from that quarter.

OF THE SUPERIORITY OF THE NORTHERN HEMISPHERE OVER THE SOUTHERN, FROM THE REV. MR. JONES'S PHYSIOLOGICAL DISQUISITIONS.

The superiority of the northern hemisphere of the world, above the southern, is very manifest. It has more land, more sun, more heat, more light, more arts, more sense, more learning, more truth, more religion. The land of the southern hemisphere, that is, the land which lies on the other side of the equinoctial line, does not amount to one fourth part of what is found on the north side.

The sun, by reason of the eccentricity of the earth's orbit, and the situation of the aphelion, makes our summer eight days longer than the summer of the other hemisphere; which, in the space of four thousand years (for so long it is since any universal change has taken place in the earth), amounts to upwards of eighty-seven years; and so much more sun has this hemisphere enjoyed than the other. What effects may have been arising gradually in all that time, we cannot ascertain; but such a cause cannot have been without its effect: and I think it is allowed, that the temperature of the earth and atmosphere, in the highest latitudes of the north, is much more mild and moderate than in the correspondent latitudes of the south. The dreary face of Statenland, with the weather-beaten Cape of South America, a climate so severe as scarcely to admit of any human inhabitants, is no nearer to the pole than the northern counties of England: but the difference in the atmosphere, and in the aspect of the earth, is almost incredible; and this is the more remarkable, because there is no mountainous country betwixt that and the pole to account for the icy blasts that prevail there.

But it is also further observable, that the northern hemisphere is better provided for by night as well as by day. The stars of superior magnitudes are much more numerous on this side the equinoctial than on the other: we have nine stars of the first magnitude, and they but four; and the stars of the Great Bear, so conspicuous in this hemisphere, having nothing to equal them about the other pole. When the sun is remote from us in the winter, our longest nights are illuminated by the principal stars of the firmament; when the sun enters Capricorn, there comes to the meridian, about midnight, the whole constellation of Orion, the brightest in the heavens, containing two stars of the first magnitude, four of the second, and many others of inferior sizes; and upon the meridian, or near it, there are four more stars of the first magnitude, Capella, Sirius, Procyon, and Aldebaran. No other portion of the heavens affords half so much illumination; and it is exactly accommodated to our midnight, when the nights are longest and darkest. If the mid-winter of the southern hemisphere be compared, the inferiority of the nocturnal illumination is wonderful.

Though it will carry us a little beyond the bounds of physics, the parallel is so glaring between the natural and intellectual superiority of this part of the world, that your time will not be lost while we reflect upon it. Here the arts of war and peace have always flourished; as if this part of the globe had been allotted to a superior race of beings. Asia and Europe, from the remotest times, have been the seats of science, eloquence, and military power; compared with which, the southern regions have ever been, as we now find them, beggarly and barbarous; possessed by people stupid and insensible, illiterate, and incapable of learning. Where are the poets, the historians, the orators, the philosophers of the southern world? We may as well search for the sciences among the beasts of the wilderness.

All the inventions, by which mankind have done honour to themselves in every age, have been confined to this side of the world. Here the mathematical sciences have flourished; printing has been found out; gunpowder and fire-arms invented; navigation perfected; magnetism and electricity cultivated to the astonishment of the wisest; and philosophy extended by experimental inquiries of every kind. There would be no end, if we were to trace this comparison through every improvement; for here we have every thing that can adorn human life, and there they have nothing.

But the difference is most conspicuous, when we compare the north and south in point of religion; to which, indeed, that pre-eminence is owing on our side, which has extended to every branch of social civilization and intellectual improvement. It is notorious at this day, that arts and learning flourish to the highest degree, in those countries only that are enlighted by christianity, and no where so much as in this kingdom, where that religion is established in its purest form. May it long continue! and may we know our own felicity in the enjoyment of it! for religion is undoubtedly the sun that gives light to the mind; the vital spirit that animates the human understanding to its highest atchievements; though many have been indebted to it, without being sensible of their obligation, or without confessing it; and others have turned against it that light which they borrowed from itself.

The northern hemisphere then, whatever preference it may have in a physical capacity, has been much more honoured by the superior advantages of learning and religion: here knowledge first began to be diffused, and the world itself was first inhabited, in the finest climates of the earth, which are about the latitudes 36 degrees, &c. north: here the church was first settled; and the Hebrew nation, rising by degrees till the reign of *Solomon*, formed a wise, wealthy, and splendid kingdom, long before the powers of Greece and Rome were heard of: here the light of Christianity was afterwards manifested, and with it the lights of learning have been extended to the parts where they were never known before, till both of them reach to the utmost boundaries of the west, in the once unknown regions of the Atlantic world.

CONCLUSION.

I have now finished my course of Lectures, and have given you a general view of the principal phenomena in nature; nor have I been inattentive to the discoveries made therein by man. I have endeavoured to point out the abuse that may be made of physical inquiries, and to guard you against the errors by which they may be perverted and rendered a prop to support the weak fabric of infidelity and falsehood. From these Lectures it evidently appears, " 1. That man is composed of two substances, of which one perceives without being perceived by the senses; and the other is perceived without having any perception in itself. 2. That man, in his present state, can perceive nothing more of the universe than what is transmitted to him by his organs, whose faculties are very limited. 3. That there are evidently effects perceptible by man, which are occasioned by beings that he cannot perceive. 4. That man deprived only of one sense, sight, would have been ignorant of the greater part of what he knows of the universe, namely, of entire classes of beings, and of the relations of these beings to each other, and to those with which he is acquainted. 5, and lastly. By every rule of analogy, and from many phenomena, it is highly probable, that there exist many classes of beings, related to each other, and to man, which he cannot in his present state perceive."*

The spiritual powers of man are roused into action by the medium of the senses. His understanding explains itself by the perceptions the senses transmit; so that, notwithstanding the extent of his powers, he can make no progress in matters higher than sense, unless he take the creation for his lesson, and the

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* *De Luc,* Lettres Physiques et Morales, tom. v. p. 11, and 689.

Omniscient Creator for his Preceptor. It is therefore weak and perverse in him, without the very elements of knowledge in his head, to desert such a wise and kind instructor, and then set up for an independent discoverer. Put the philosopher to the trial, who pretends to know so much of a Deity without allowing him to discover himself and explain his own works, and you will soon see the wise man confounded by his own wisdom. If this wanted proof, I need only mention the writings of *Helvetius*, *Voltaire*, *Diderot*, *De la Metrie*, and the whole school of *Condorcet*.

In contradiction to these men, I have endeavoured to shew that philosophy is illustrated, and just views of nature are exhibited by the sacred writings. What indeed can we think of those who would have us believe they credit the scriptures, while they take upon them to correct its stile, as not philosophically just? who would have us believe, that HE who holds all nature in his hand, does not know how to accommodate his doctrines to the capacities of the vulgar, without speaking with philosophical impropriety of his own works? Will they, indeed, teach HIM to speak, who gave a mouth to man, whose word was sufficient to cause the mighty sun to shine, and daily diffuse his treasures of light around the heavens, irradiating the shifting hemispheres of the revolving earth, and at whose command it is surrounded by the liquid air? Shall the writings of men have excellencies in our eyes, and HIS have no beauty, who hath meted out the heavens, who knoweth the ballancing of the clouds, and by whose knowledge the deeps are broken up?

Both HIS word and HIS works prove, that he has employed and displayed infinite wisdom, power, and goodness, in the creation of this universe; that HE has with stupendous artifice stored our globe with every thing necessary, not only for the support, but for the felicity of man: all HIS works are stamped with the characters of the infinite perfections, and overflowing goodness of the AUTHOR. HE has given to man, and to him alone, a capacity to be entertained with the magnificence, the beauty, the harmony, and the order of the universe; and has so moulded his heart and spirit, as to make pleasure attendant on admiration, and love and gratitude the necessary companions of the senses of favours received.

Let us then praise the God of heaven, from whom we have received so much, whose mercy is extended over all.

Let every thing that hath breath praise him; and let man, the priest of the creation, offer up a sacrifice of thanksgiving unto the MOST HIGH.

APPENDIX TO LECTURE LII.

BY THE EDITOR.

CONTAINING A FURTHER DESCRIPTION OF METEOROLOGICAL INSTRUMENTS; WITH FIGURES.

THE barometer, as already described by our Author, page 477, *et seq.* is called the *chamber barometer* When the instrument is constructed to be used at sea, on board a ship, it is called the *marine barometer*, and which is made somewhat different from the chamber one, in order to prevent the violent concussions of the mercury on the top of the tube, and the unsettled state of its altitude, caused by the motion of the ship. There have been various contrivances to obviate these; but the best appears to me, to consist in drawing about two feet of the lower portion of the barometer tube to a fine aperture, almost capillary: the resistance so occasioned to the motion of the mercury in the tube, is found sufficient to retard and destroy a violent motion, and to produce a just altitude of the mercury. It requires a little longer time for the settling of the mercury to its true altitude, but which is of no consequence to the observation.

The frame of the instrument is suspended on gimbals near to the center of gravity, and occasionally to be screwed either to the ceiling or side of a cabin; and from these positions the instrument has been found to answer sufficiently well all the purposes for which it is wanted at sea. Fortunate is it for the mariner, when by the alterations of the altitude of the mercury he can foretel the approach of a storm, or tempestuous state of the atmosphere.

The instrument should be accompanied with a thermometer.

A BAROMETER TO MEASURE THE HEIGHTS OF MOUNTAINS, DEPTHS OF VALLIES, HEIGHTS OF BALLOONS, &c. &c.

The barometer has been found to be the most convenient and accurate instrument that can be used for these purposes. By experiments made by M. *de Saussure, de Luc*, and Sir *George Shuckburgh*, it appears that heights and depths have been ascertained to a few feet in several thousands. The instrument requires to be made with the utmost accuracy, and great diligence and attention paid to the adjustments, &c. during the observation. The tube of this sort of barometer has its lower extremity drawn out to a small aperture; a floating index applied, so as to be depended upon to at least the 500th part of an inch, as a gage point; the frame made very light either of wood or a brass tube; the scale of inches extended downwards to about 17 or 18 inches, and a portable mahogany tripod with folding legs with gimbals, made to support it when in use, or serve as a case for the instrument when not in use.

To measure heights, &c. in the most accurate manner, the observer must be provided with two barometers, or in case of an accident, with a third: the nonius or sliding plate to the scale of inches should subdivide it into the 500th part at least. There should be a thermometer attached to each instrument, and two detached correspondent ones for the pocket. The manner of making observations and computing from these instruments, the reader will see in Sir *George Shuckburgh*'s account in the Philosophical Transactions, vol. 67 and 68.

Geometrical measurement with the assistance of good angular instruments is the best method, when a good base is afforded; but, as few countries afford a suitable base or favourable circumstances in the figure or situation of the mountains to be measured, the barometer is the instrument most frequently adopted.

DE LUC'S HYGROMETER.

M. *de Luc*'s hygrometer, made of a fine slip of whalebone, is the most approved instrument of the kind, and in the most general use. It has been found by him of greater expansibility than any other substance, such a slip lengthening about one-eighth of itself from extreme dryness to extreme moisture; it is a substance easy to be cut into slips; and they have been made so fine, as in a length of six or eight inches to weigh only one-tenth of a grain; on this account it is the most suitable substance for a common hygrometer.

Fig. 1 of the following page shews its form as now made for common use; it is made of various dimensions, but the figure is about one-half the size

Fig. 1.

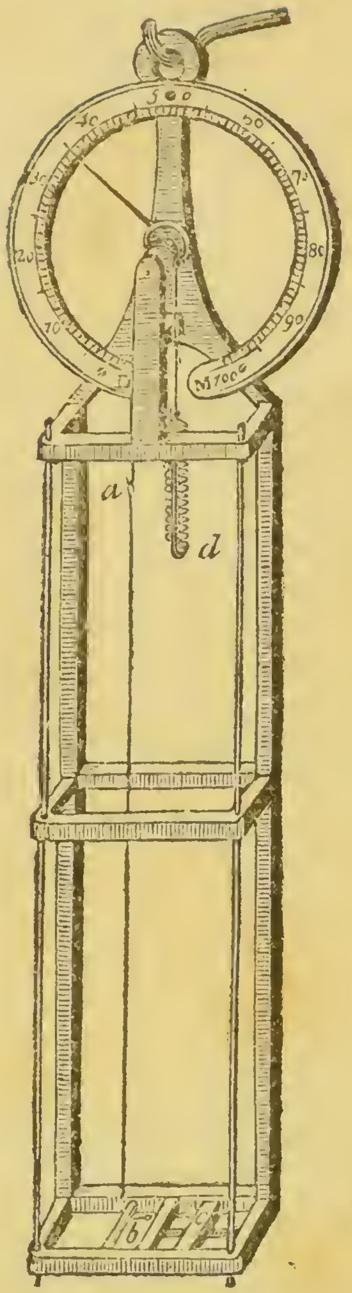


Fig. 2.

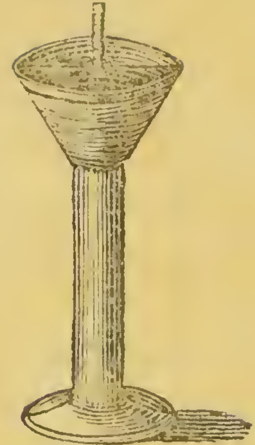


Fig.3.

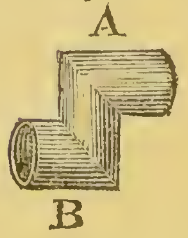
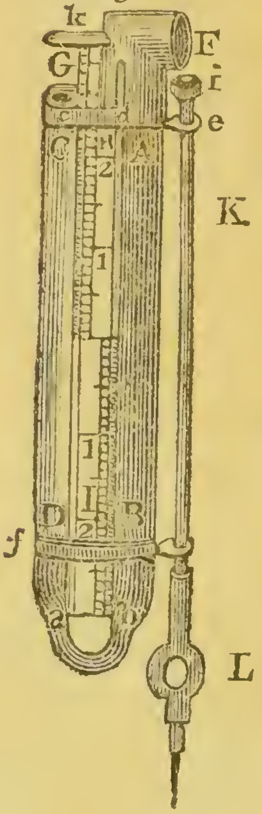


Fig 4.



of those generally made. The frame-work is of brass, lightly made, and can easily be understood by the figure, without a detailed description here. The slip of whalebone is represented by *a b*, and at its end, *a*, is shewn a sort of pincers made of flattened bent wire, tapering in the part that holds the slip, and pressed by a sliding ring. The end, *b*, is fixed to a moveable bar, *c*, which is moved by a screw for adjusting first the index on the dial ring. The end, *a*, of this slip is hooked to a thin brass wire, to the other end of which is also hooked a very thin lamina that has at that end pincers similar to those of the slip, and which is fixed by the other end to the axis of a pin in a proper hole. The spring, *d*, by which the slip is stretched, is made of silver gilt wire; it acts on the slip as a weight of about twelve grains. The central pulley or axis has very small pivots, the shoulders of which are prevented from coming against the frame by their ends being confined, though freely, between the flat bearings of two screws, the fronts of which appear in the figure. The dial ring at top is divided into 100 equal parts, shewing the expansion of the slip from extreme dryness, marked D, to extreme moisture, marked M.

A principal nicety in constructing the instrument is in so proportioning the diameter of the axis or pulley, that this whole expansion may exactly commensurate the circumference of the ring, as pointed out by the index. The form of the instrument as now described adapts it chiefly for use within doors. For exposure at the outside of a window, the slip of whalebone is generally inclosed within an half brass tube perforated with two vertical rows of large holes, and a whole tube is made to go over this half one, which has also two vertical rows of holes at such a distance from one another, that when one of them corresponds to one of the rows of the half tube, the other is in front. The rows of holes of the tube are to be turned towards the room to prevent the rain from falling on the slip, and the dial with the axis and index being included in a box with a glass in front, no rain can get into the instrument. It must also be fixed in a place not much exposed to the sun, or be screened from it without preventing the circulation of the air.

In the preparation of the slip of whalebone, the points of extreme dryness and extreme moisture are to be carefully ascertained. The former M. *de Luc* directs to be had by means of large pieces of quick-lime, taken from the kiln and suffered only to lose the red heat, put into a lime vessel; and the latter, simply by immersion in water.

The best lime vessel M. *de Luc* constructed and contrived, is as follows: it consists of two tin vessels, the first of which and the most used is 16½ inches high, 15½ inches wide, and 5 inches deep. The front of this vessel is a plate of glass, and the back a tin plate slider, which being taken off, leaves that side of the vessel quite open. The second vessel has the same dimensions as the first, but its back is soldered, and its front is of woven brass wire. This vessel may be applied to the back of the former, in such a manner as to make of both one single vessel; which, when the slider of the fore part is taken off, is only divided by a vertical partition of the woven brass wire. The use of that second vessel is to produce extreme dryness in the other, for which purpose it is filled with large pieces of quick-lime taken from the kiln. When that vessel is not used, it is kept in a tin box which it fills entirely; and when it is in, as well as while it is out for use, that box is kept shut with putty, by which means the lime may serve many times, in the following manner: when I want to produce extreme dryness in the first vessel, says M. *de Luc*, I apply it to the second, fastened with hooks; I then pull out the slider of the first, and stop with putty the chinks between them. When that first operation is completed, I put again the slider to the fore vessel, and take off the other. In this last operation, some moisture might be introduced through the chinks of the slider before they are again stopped with putty, especially as the destruction of the air in the vessel has made room for more air to come in; but I prevent it, by making first the apparatus sensibly warmer than it was when I put on the lime vessel; by which means, in the little time employed for the operation, the motion of the air is from the inside to the outside, which prevents all access of moisture in the vessel.

On the top of this vessel may be made square openings with close shutters, and withinside just underneath a wire fastened across with several hooks, upon which are to be suspended hygrometers to be adjusted to extreme dryness. A few hours is the time generally necessary, but of this the practitioner can very readily judge.

This vessel was constructed by M. *de Luc* to assist in his experiments on the comparative changes of weight and dimensions of some hygroscopic substances, but it is equally useful for the purpose of adjusting the hygrometers.

For a description of an other previous vessel for this purpose, as well as a valuable paper on the subject of hygrometry by M. *de Luc*, see the Philosophical Transactions for 1791.

SIX'S IMPROVED THERMOMETER.

The late ingenious Mr. *Six* constructed a thermometer that was a self-register of the extreme degrees of heat and cold during the observer's absence. It is properly a spirit of wine thermometer, with mercury connected to support two indices acting upon it in two different tubes. Each index acts by a spring within the tubes, so that being pressed up to particular divisions by the extremes of heat and cold acting on the spirit, they remain there for the observer's inspection; the indices being chiefly made of inclosed steel, a small artificial magnet applied to them, will bring them down to the surface of the mercury for a fresh observation.

This thermometer is somewhat difficult to be constructed from the impracticability of obtaining equable bores of the glass tubes for the action of the indices, as a small irregularity will generally obstruct their rise by the action of the mercury. It requires a considerable draught of tubes to obtain a few sufficiently true, and then they are subject to be broken in the formation. See Mr. *Six*'s Treatise on the Thermometer, 8vo. 1794.

RAIN GAGE.

Fig. 2 is a representation of the rain gage as now generally adopted, and already described by our Author at page 500. The funnel at top may be either square or round, but the former perhaps is more convenient. The proportion of the area of the top of the funnel to the cylinder, in which the rain descends, is as 9 to 1; the diameter of the former being 12 inches and the latter 4 inches; the scale of the floating index is therefore in its divisions into inches extended 9 times, and 9 inches is divided into 100 parts, from which the fall of rain to the $\frac{1}{100}$th of an inch can be readily estimated. A small pipe near the bottom of the cylinder, stopped with a cork, is usually applied to discharge the cylinder of the water when quite filled by the rain.

WIND GAGE.

A wind gage, or instrument to measure the force of the wind upon any given surface, is an article of a very useful nature, and a perfect sort of one appears yet to be wanting to complete the arrangement of meteorological instruments. A gage invented by Dr. *Lind* appears to be the best and most convenient yet contrived; *fig.* 4, is a representation of the instrument. It consists of two glass tubes, AB, CD, of five or six inches in length, with equable bores of about four-tenths of an inch in diameter; they are joined together by a narrow tube *a b*, drawn out of the larger ones, having a bore of about one-tenth of an inch diameter. On the top of A B is fixed a brass tube bent outwards with its mouth open towards F. On the other leg, C D, is cemented a cover, with a round hole, G, in the upper part of it, two-tenths of an inch in diameter; this cover and tube are connected together by a slip of brass, and serves to hold the scale and strengthen the whole instrument. To the same tube is soldered a piece of brass *e*, with a hole to receive the brass spindle K L; and at *f* there is another piece of brass, surrounding and steadying the glass tubes.

There is a shoulder upon the spindle at *f*, upon which it rests and turns, and a nut at *i*, to prevent its being blown off the spindle by the wind. The instrument is turned round upon the spindle by the wind, so as always to present the mouth of the tube towards it. The lower end of the spindle is formed to a screw, by which it may be fastened to a post or other proper place. It has a hole at L, to admit a small lever for screwing it by with more readiness.

A thin brass plate, *k*, is fixed on the tube above the round hole G, to prevent the admission of rain. There is also a bent tube A B, *fig.* 3, to be put occasionally on the mouth of the tube F, to prevent the admission of rain into the gage, when left exposed.

The force or momentum of the wind may be ascertained with the assistance of the instrument, by filling the tubes half full of water, and sliding the scale a little up or down till its 0, when the instrument is in a perpendicular position, be in a line with the surface of the water in both tubes. The instrument being thus adjusted, hold it up perpendicularly, and turning the mouth of the tube towards the wind, observe how much the water is depressed by it in the one leg, and raised in the other. The sum of the two is the height of a column of water, which the wind is capable of sustaining at that time; and every body that is opposed to that wind will be pressed upon by a force equal to the weight of a column of water, having its base equal to the altitude of the column of water sustained by the wind in the wind gage. Hence the force of the wind upon any body, where the surface opposed to it is known, may be easily found, and a ready comparison may be made betwixt the strength of one gale of wind and that of another.

The force of the wind may be likewise measured with this instrument, by filling it till the water runs out at the hole G. For if it is then held up to the wind, a quantity of water will be blown out, and if both legs of the instrument are of the same bore, the height of the column sustained will be equal to double the quantity of water in either leg, or the sum of what is wanting in both legs. But if the legs are of unequal bores, neither of them will give the true height of the column of water, which the wind sustained; but the true height must be found by a formula given by Dr. *Lind* in the Philos. Trans. vol. vii. or the Encyclopœdia Britannica, vol. lxv. page 524, edition 1797.

END OF VOL. IV.